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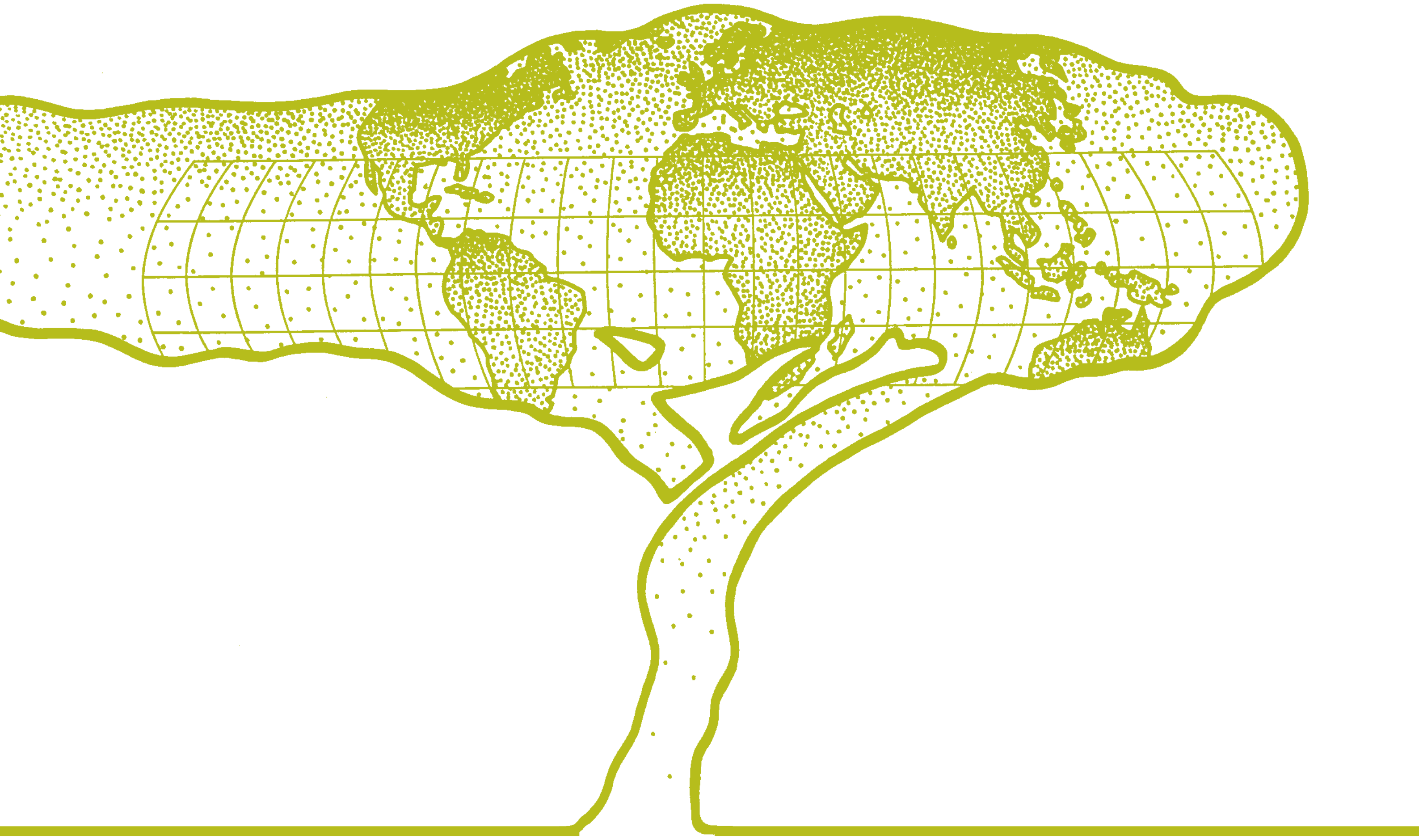

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**Is prosopis a curse or a blessing? – An ecological-economic analysis of an invasive alien tree species in Sudan**

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# TROPICAL FORESTRY REPORTS

TROPICAL FORESTRY REPORTS contains (mainly in English) doctoral dissertations, original research reports, seminar proceedings and research project reviews connected with Finnish-supported international development cooperation in the field of forestry.

**Publisher** Viikki Tropical Resources Institute (VITRI)
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(address for exchange, sale and inquiries)

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**Cover Design** Lesley Quagraine

Suggested reference abbreviation:
Univ. Helsinki Tropic. Forest. Rep.

# Is prosopis a curse or a blessing? – An ecological-economic analysis of an invasive alien tree species in Sudan

**Jörn Laxén**

*Academic dissertation*

*To be presented, with the permission of the Faculty of Agriculture and Forestry of the University of Helsinki, for public discussion in Auditorium XII of the University Main Building, Fabianinkatu 34, on Friday 27 April at 12 o'clock noon*

Helsinki 2007

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**ABSTRACT**

The overall aim of this work was to develop scientifically verified and realistic solutions for the quantification of impacts and a further ecological (environmental) economic valuation of benefits and social costs of prosopis (*Prosopis juliflora*) in Sudan. A Presidential Decree from 1995 to eradicate the prosopis tree from everywhere in Sudan due to its conceived overall net detrimental impacts constituted a demanding challenge to investigate whether this view on the species is true or false. This is a long-standing issue of hot debates in numerous other countries in the tropics and sub-tropics as well.

The research methodology primarily, consisted of a problem-based approach that emphasized economic analyses which utilized, where available, the market economic values at two case study sites framed inside the New Halfa and the Gandato Irrigation Schemes, respectively. Additionally, the derivation of non-market values was captured using ecological economic tools, so as to reach a deeper understanding on how prosopis impacts on the environment and on the human well-being at the two study sites.

The main data collection in the New Halfa Scheme framed area in Kassala State was first conducted as four separate household surveys (totally with 110 sample households) for the tenant farmers, the western and the eastern Sudanese landless people, as well as for the nomad population group, respectively. The latter three comprised several ethnic groups. Due to the complexity caused by a diversity of the population groups, the main aim at New Halfa was to study the magnitude of environmental economic benefits and costs, derived from the invasion of prosopis in a large agricultural irrigation scheme on clay soils. A comparison was also made between a prosopis-invaded framed area and an area totally devoid of prosopis in the same scheme.

In New Halfa, there was a distinct and slowly decreasing trend from the poorest towards the richest households in the dependence on prosopis among the western and eastern Sudanese landless groups as well as among the nomads. For the western Sudanese landless population, prosopis was a substantial cash income source, and for all landless groups it was important for the subsistence income in the form of free-grazing forage, wood energy, and construction materials. Although many landless households considered themselves as farmer families, their income related to prosopis was larger than their crop cultivation income. In contrast, for the tenant farmers prosopis considerably reduced the profits from crop cultivation, due to the increased expenses for ploughing the prosopis-invaded irrigated fields and for the maintenance of irrigation canals. It also caused costs for employing labour for weeding and the cutting of trees, and in the form of thorn injuries that sometimes needed medical attendance. However, the tenant farmers also had benefits from the prosopis-based free-grazing forage and from fuelwood. Although prosopis products could be obtained free of charge directly by the households, many of them voluntarily chose to purchase charcoal, fuelwood and poles.

The valuation in the New Halfa Scheme identified partly different benefits and costs as compared to the Gandato Scheme, and the results are not as clearly in favour of prosopis, although a Benefit/Cost Ratio of 2.1 could be concluded for this area.

There were several reasons for the different situation in benefits and costs derived from prosopis in the New Halfa Scheme as compared to the Gandato Scheme: (a) a more complex population background in New Halfa, leading to varying benefits and detriments for each group; (b) prosopis actually growing inside the agriculture scheme, which was not a preferred situation; (c) a soil which mainly consisted of clay; thus the potential beneficial impacts from protection from sand invasion

were not needed; (d) other tree species which could be grown inside the scheme but which would have needed more tending than prosopis; and (e) prosopis causing much more detrimental impacts on the operational costs for agriculture in this scheme as compared to the Gandato Scheme case. The final decision whether prosopis is suitable in the New Halfa Scheme thus cannot be made on purely scientific grounds. A serious attempt to eradicate prosopis from the scheme has recently been made after the data collection for the present study.

The framed research site selected in the Gandato Irrigation Scheme near Shendi in the southern part of River Nile State had a more homogenous population. Here the former pastoralists had had to settle permanently in the area when the increasingly arid environment did not any more support a pastoral lifestyle. This site represented the kinds of impacts from prosopis that a medium-size irrigation scheme was confronted with on sandy soils in the arid and semi-arid ecozones along the Nile. The household survey here comprised 70 households from the whole population as one sample group in the framed area. A Total Economic Valuation (TEV) study was conducted based on the household survey and other studies from the Gandato Scheme which showed, apart from the invasion of prosopis, also a severe encroachment of sand in some of the villages studied.

For the Gandato Scheme framed area, a monetized benefit-cost ratio of 46 was derived for the prevalent situation. This ratio still excluded several additional beneficial impacts of prosopis in the area that were difficult to quantify and monetize credibly within the current research work. The same kind of a net beneficial outcome for prosopis could be assumed to exist for the more than 1000-km stretch of the riverine ecozone from Kosti in the White Nile up to the Egyptian border. In River Nile and Northern States the beneficial impact can be seen as completely outweighing the costs of prosopis. For the human population in the Gandato area, prosopis was a small cash expense and cash outlay for almost every household in the area. The annual monetized net benefit from prosopis for each household was 607,000 SD. The livestock population in the area would collapse to about half of the current number without a prosopis forage opportunity.

Further ecological (or environmental) economic valuations on the importance of prosopis in the arid and semi-arid ecozones in Sudan or elsewhere should be implemented using site-specific, scientifically verifiable, realistically monetized values. In particular, it would be essential to distinguish between the sand soil and the clay soil conditions. Impacts which are clearly “positive” but difficult to monetize credibly also have to be described and listed. Credible values should be based on statistically representative samples of the economic premises of the local households and on their interaction with the micro-economic markets at the study site. Furthermore, the practical element is important, since the valuation approaches should also be easily applicable, fast to execute, and affordable for the authorities and the managers.

**Key words:** Prosopis, ecological economic valuation, environmental economic valuation, irrigated agricultural scheme, arid and semi-arid ecozone, Sudan.

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# PREFACE

Sudan has since the early 1980s been one of the main countries where researchers at Viikki Tropical Resources Institute (VITRI) have been conducting tropical forestry research work. I was among the young students of VITRI who during the late 1980s were selected for M.Sc. thesis field data collection in Sudan. My M.Sc. thesis concerned ecophysiology of *Acacia senegal* in the Tendelti region of Sudan. Upon graduation in the early 1990s I became first employed at VITRI by a University of Helsinki-owned consulting company for whom I functioned as a project liaison officer coordinating, under professor Olavi Luukkanen's supervision, VITRI's ongoing tropical forestry projects. Already at the time of my M.Sc. studies there was an idea in the back of my mind to continue for a higher academic degree combining forest ecology, forest economics and the environment in some way, but a suitable concrete approach for doing this was not yet identified. Instead, work at the consulting company took over completely, and the researcher became a consultant operating mainly from the company's home office in many parts of the world and in a multitude of disciplines and projects financed by a wide range of international financing institutions. One such new discipline I worked in was environmental economic valuation, which started to interest me.

In 2001 several researchers from VITRI made contact with me at the consulting company and a new interest for collaboration with VITRI arouse. Later that same year in a discussion with Dr. Mohamed ElFadl the issue of *Prosopis juliflora* in Sudan and the Presidential Decree to eradicate it was mentioned. I decided to take up the thrown-in challenge to study the suitability of prosopis in Sudan using an environmental economic valuation approach to the topic. In June 2002 VITRI was inaugurated as a reorganised and re-named institute at the Faculty of Agriculture and Forestry at the University of Helsinki and a new project director position with some funding was reserved at the institute in order to boost project tendering and management activities. As the person chosen to the position I was also able to begin my new research activities.

I would like to express my deepest gratitude to Professor Olavi Luukkanen for providing the work opportunity at VITRI for me, while at the same time allowing me to carry out higher academic studies in tropical forestry-related environmental (ecological) economics. Without his encouragement and support I would not have been ready to return back to the academia. Similar gratitude goes also to Professor John Sumelius at the Department of Economics and Management, who has acted as my co-supervisor. After the initial assistance and various views on how the work should be conducted he let me develop the thesis work based on my previous professional and developing country experience. Later, once the direction of the thesis work could be better distinguished, he became more closely involved again and provided me with full support, many useful thoughts and clarifications for finalizing the work. I am also indebted to the two official scientific reviewers, Professor Jussi Uusivuori and Dr. Marko Katila, for all their valuable and constructive comments.

A personal tailor-made micro-economics and environmental economics course organised for me by Professor and Vice-Rector Olle Anckar at the Faculty of Economics at Åbo Academi University within its adult education programme prepared me at the outset. My deepest gratitude goes to him for believing in my ability and in upgrading my environmental economic skills to a level where I could start taking more advanced courses at the University of Helsinki.

I would also like to thank my current and former colleagues at VITRI working with research in Sudan and Ethiopia. Dr. Mohamed ElFadl has provided me with invaluable support through numerous discussions, organizing leisure activities in Sudan, contacts, logistics, reference literature and other issues that greatly assisted me in fulfilling this research effort. Dr. Abdallah Gaafar Mohamed, Dr. Elamin Raddad and Dr. Eshetu Yirdaw also supported me in similar ways. Dr. Abdallah Gaafar Mohamed carried even out some interviewing work for me on resettled households in Khartoum. Kurt Walter assisted me during the first data collection trip to New Halfa and Shendi when we together conducted the household surveys which Kurt used for his M.Sc. thesis while I collected the data presented in this particular thesis. Juhana Nieminen from the Department of Forest Resource Management helped me tremendously with satellite image purchasing and preparation.

In Sudan there are numerous foresters and other professionals who have heavily supported the work. My deepest gratitude goes to Dr. Abdelazim M. Ibrahim, Managing Director of the Forests National Corporation (FNC) and his wife Dr. Huda Sharawi, professor of forest economics at the University of Khartoum. Both are my former colleagues from my first work period at VITRI in the early 1990s. The professional and logistics support of Dr. Abdelazim and his FNC staff has been crucial for conducting of this research work. Mamoun Musa at the headquarters and the FNC staff in the Shendi office - Kamal, Negwa, Hoida and Adil – also need special mentioning. They provided crucial support to the data collection in Gandato through their friendship, logistics, translation during interviews and transportation. Many other foresters, technicians and drivers from FNC supported my work throughout my missions in various parts of Sudan.

Of the forest researchers in Sudan, the Director of the Forestry Research Centre, Professor Ahmed A. Salih, stands out particularly. He has put down large amounts of his time and efforts to support VITRI researchers' work in Sudan. His staff in Soba and elsewhere also supported this present work. In addition, there were also academics of the Faculty of Forestry at the University of Khartoum who supported me. Dr. ElNour ElSiddig stands in a category by himself in this regard. He spent a lot of time in Khartoum, in the field and even during his six-months stay in Finland going through my research concepts, particularly during the initial stages of the research work. Some forestry graduate students from Khartoum University, especially Mustafa Abbas, acted also as my interpreters during interviews with local people.

I have also enjoyed the company and support from many others in VITRI staff, including Dr. Vesa Kaarakka, Dr. Anu Eskonheimo, Dr. Eddie Glover, Dr. Minna Hares, Dr. Riikka Otsamo, Dr. Mark Appiah, and, among the doctoral students, Sakina ElShibli, Ping Zhou, Loice Omoro, Maarit Kallio, Syed Alam, Pia Katila, Teija Reyes and Fobissie Kalame. There were also some M.Sc. students involved in the Sudan project team, of which Talvikki Aittoniemi should be mentioned in particular, as many others have already been mentioned above relation to in their current status as doctoral students.

Finally I am deeply indebted to my parents Torolf and Ulla Laxén for all encouragement and understanding during the whole working process. Especially my father has had the professional experience to be able to provide constructive criticism when needed.

Helsinki, March 2007
Jörn Laxén

## ACRONYMS

| | |
|---|---|
| ADB | Asian Development Bank |
| CBA | Cost-Benefit Analysis |
| CBD | Committee on Biological Diversity |
| CDM | Clean Development Mechanism |
| CVM | Contingent Valuation Method |
| EA | Environmental Assessment |
| EIA | Environmental Impact Assessment |
| FAO | Food and Agriculture Organisation of the United Nations |
| FNC | Forests National Corporation |
| GPS | Global Positioning System |
| ICRAF | World Agroforestry Centre (International Centre for Research in Agroforestry) |
| IEE | Initial Environmental Examination |
| IRR | Internal Rate of Return |
| IUCN | International Union for Conservation of Nature |
| LULUF | Land use, land-use change and forestry (carbon sequestration project) |
| MAI | Mean Annual Increment |
| MEPH/HCENR | Ministry for Environment and Physical Planning/ Higher Council for Environment and Natural Resources |
| MfFA | Ministry for Foreign Affairs of Finland |
| NEAP | National Environmental Action Plan |
| NEPAD | New Partnership for Africa's Development |
| NGO | Non-governmental organisation |
| NPV | Net Present Value |
| NWFP | Non-wood forest product |
| PROFOR | Program on Forests (a multi-donor partnership housed at the World Bank) |
| PRSP | Poverty Reduction Strategy Paper |
| SFM | Sustainable Forest Mnagement |
| SIA | Social Impact Assessment |
| SOM | Soil organic matter |
| TCM | Travel Cost Method |
| TEV | Total Economic Valuation |
| UNCCD | United Nations Convention to Combat Desertification |
| UNCED | United Nations Conference on Environment and Development |
| UNDP | United Nations Development Program |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNFF | United Nations Forum on Forests |
| VITRI | Viikki Tropical Resources Institute at the University of Helsinki |
| WB | World Bank |
| WHO | World Health Organisation |
| WSSD | World Summit on Sustainable Development |
| WTP | Willingness to pay |

**Measurements:**

| | |
|---|---|
| SD | = Sudanese Dinars = 1/261 USD ($) = 1/310 Euro (€) (August 2003 exchange rate) |
| Feddan | = 0.42 ha (hectare) |
| Kantar | = 44.39 kg |

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# 1. INTRODUCTION

## 1.1. Background

Poverty reduction and desertification are two major challenges facing the world that are often linked, especially in developing country contexts. Both issues are currently among the central themes of most international development programmes, such as the United Nations Convention to Combat Desertification (UNCCD) and the New Partnership for Africa's Development (NEPAD). The World Summit on Sustainable Development (WSSD) held in Johannesburg, South Africa, in September 2002 also had these topics as the most important cross-cutting issues. Speakers at the WSSD conference considered that sustainable development in drylands might not even be possible without a simultaneous poverty reduction and combatting of desertification (Hoffman 2003; Garrity 2004; UNCCD 2004).

Apart from the issues of poverty reduction and desertification in arid and semi-arid areas there are several other challenges inter-twinned with the above mentioned ones, particularly as related to the environment. Such environmental challenges are diverse in character and include, for instance, the over-exploitation of vegetation; water and soil pollution problems; human and livestock population growth pressures on land use and tenure; and problems with various kinds of invasive species.

Already in the 1960s Sudanese foresters were introducing the locally adapted prosopis tree to many densely populated rural areas in various parts of Sudan, such as the agricultural irrigation schemes and the suburban areas of major towns, as a shelterbelt tree to ensure a sufficiency in fuelwood and other wood products that slow-growing native tree species were unable to provide (ElSiddig et al. 1998). In the 1980s several internationally financed afforestation and reforestation projects were established in various parts of central and northern Sudan, and some of these projects included independent species trials. For instance, the SOS Sahel, a UK based NGO, and the Sudan-Finland Forestry Programme (SFFP) funded by the Finnish bilateral development aid both tested about 20 different tree species and varieties for arid and semi-arid field conditions, and in each trial the locally adapted prosopis performed well (Saarainen and Luukkanen 1991; Bristow 1996; Mutsambiwa et al. 1998; Laxén et al. 2005). In the early 2000s prosopis had been introduced in about half of the total of 26 states which constitute Sudan[1].

During the early 1990s a popular opinion in parts of central Sudan and within the Sudanese Government had begun to consider prosopis a noxious weed and a problematic tree species due to its aggressive ability to invade farmlands and pastures, especially in and around irrigated agricultural lands. As a consequence prosopis was deemed an invasive alien species, and on 26 February 1995, a presidential decree for its eradication was issued, which was followed by campaigning to execute the eradication. In many sandy areas outside irrigation schemes, and particularly in Northern and River Nile States, the eradication decree came as a total surprise to the local communities as well as to the NGOs and foresters involved in the extension activities to promote prosopis. Many of these promoting extension workers experienced this as a reduced credibility from which they still in 2004 had not recovered. During the last decade, there have been several meetings and workshops, often coordinated by foresters, aimed at analyzing the prosopis situation more objectively**.** Although the meetings have involved a large variety of professionals, researchers, managers, politicians at various levels, non-governmental organisations, as well as

[1] Personal communication by Mr. Talaat D.A. Mageed, National Coordinator of Prosopis at the FNC in January 2003.

community people, no concensus has been reached and the prosopis eradication issue has increasingly become a priority on the political agenda (ElFadl and Luukkanen 2006).

## 1.2. Aim of the Study

The Presidential Decree to eradicate prosopis from everywhere in Sudan due to its conceived overall net detrimental impacts constituted a demanding challenge to investigate thoroughly and to conclude whether this view on the species is true or false. The aim was to develop scientifically verified and credible solutions for the valuation of the benefits and costs of prosopis in Sudan that eventually could be generalized to suit decision-makers elsewhere as well. The research methodology emphasized various economic analyses which utilized, where available, market economic values supported by ecological economic tools in order to verify, adjust and develop a holistic and integrated picture of the economic values of *Prosopis juliflora* at two selected case study sites. Further, the results were expected to provide management support to other parts of arid and semi-arid Sudan as well as to other countries where decision-makers are faced with similar challenges from prosopis. The task constituted a challenge as at the outset there were neither previous research models available for the work, nor much previously collected data suitable to support an ecological economic analysis of prosopis in Sudan.

The existence of prosopis in an area needs to be valuated based on its all effects on the local population in order to tie it into the local decision-making processes and economy. It is a well-established fact that in many places in arid and semi-arid ecozones of Sudan prosopis forms, where it exists, the only, or at least an important, part of the freely available wood resource for the local households. Therefore it is necessary to examine how prosopis in combination with all available natural resources impacts on the local rural household economies. This was the primary angle for this particular study.

The specific objectives for the research were the following:

- To assess the impacts of *Prosopis juliflora* on household livelihoods and the income share derived from prosopis for each specific population group in two selected contrasting and representative research areas;
- To prepare a Total Economic Valuation (TEV) study for prosopis on sandy soils at one of the two selected framed research areas;
- To study the current magnitude of ecological (environmental) economic and socio-economic benefits and costs *of P. juliflora* in the other selected framed research area.

The study was based on the assumption that prosopis has different benefits and costs at different site conditions in Sudan, and this basic assumption was reflected in the selection of the two representative research sites.

### 1.3. Structure of the study

The *Introduction* (Chapter 1) opens the main research topic of this study through a short description of the on-going debate on prosopis in Sudan and its consequences for the rural population in semi-arid and arid lands. Chapter 1 further presents the aims of the study. The basic assumption strives to provide a red thread throughout the whole research work, while the actual theoretical framework and a valuation work is presented with tailor-made approaches for each research stage and valuation exercise separately later on in the text. The chapter further describes the structure of the study.

The *Overview of the Prosopis Problem Context in Sudan* (Chapter 2) dwells first on the overall environmental setting in the Sahelian drylands and in Sudan in particular and continues then with an introduction to the prosopis tree from a historical viewpoint with a presentation of the species and its utilization, and further with discussing its usefulness versus its weediness. The chapter ends with an elaboration on sustainable development in drylands in Sudan.

The *Theoretical Framework* (Chapter 3) presents the overall strategies and approaches used for the achievement of the aims presented in Sub-Chapter 1.2. It further outlines the various research steps needed for the data collection and the Total Economic Valuation (TEV) exercise. The Chapter further elaborates the potential valuation approaches of the study and on standardizing of income measures for the household economic information needed as data for the TEV.

The *Material and Methods* section (Chapter 4) describes the selection of representative research sites and the screening process for identifying relevant impacts for the valuation work. The chapter further presents the two selected research sites and the specific methodologies used in connection with the household economic surveys. Furthermore, the chapter presents the outline of the whole research process and the outline for ecological economic valuation exercises conducted in the TEV. The valuation exercises are also presented with their bases for calculation and their respective valuation approaches.

The *Results* (in Chapter 5) consist of three sets of research findings. The chapter presents first the various household economic results from the New Halfa Irrigation Scheme for each population group separately and then it synthesizes the results for the whole framed research area; that eventually leads into a calculation of the monetized magnitudes of impacts from prosopis. The second set presents the findings from the household economic survey conducted in the Gandato Irrigation Scheme. The third and largest set presents a three-scenario analysis of the results from the TEV for the Gandato framed area.

The *Discussion* (Chapter 6) synthesizes and discusses first the overall livelihood situations in the framed areas of the New Halfa and Gandato Irrigation Schemes, the TEV valuation approaches and the malaria vs. tree link in irrigation schemes. Secondly it further discusses from a holistic viewpoint the current environmental setting and management of the Sudanese drylands and how prosopis is fitting into this setting. The *Conclusions* (Chapter 7) present briefly the main findings and recommendations derived from the research work.

# 2. OVERVIEW OF THE PROSOPIS PROBLEM CONTEXT IN SUDAN

## 2. 1. Environmental hazards facing drylands

### 2.1.1. Dryland desertification in Africa

The United Nations Conference on Environment and Development (UNCED) in 1992 in Rio de Janeiro put the environmental issues properly on the international agenda. At the conference, desertification was formally defined as “land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities” (UN General Assembly 1992). Desertification was seen to cover accelerated soil erosion by wind and water, increasing salinization of soils and near-surface groundwater supplies, a reduction in soil moisture retention, an increase in surface runoff and stream flow variability, a reduction in species diversity and plant biomass, and a reduction in the overall productivity in dryland ecosystems with subsequent impoverishment of the human communities dependent on these ecosystems. Severe social disruptions, emigration and famine are also acute combined effects of dryland degradation and climatic stress (Williams 1995).

Climate change is likely to impact seriously on the Sahel where, according to some studies, precipitation has dropped considerably since the mid 1950s and the decrease in precipitation has contributed to large human and economic losses. An increased intensity of droughts and floods and changes in growing seasons in the Sahel may have significant implications for soil productivity, water supply, food security, and human welfare, as well as deleterious and often irreversible impacts on the biological diversity. It is anticipated that a change in climate in the region will result in more adverse socio-economic impacts related to the vulnerability of society and the sensitivity of the environment. Population factors such as high population growth rates, restricted population movement, poor health standards and low material standards make African countries particularly vulnerable (Salih 2000). The above occurs in combination with a low institutional and financial capacity to adapt to changes. For Africa, the recommended adaptation strategy is to focus mainly on preventive measures such as adaptation policies for the development of natural ecosystems, forests, agriculture, livestock, water resources, coastal zones and energy, and on socio-economic factors such as population growth, health, and infrastructure (Williams 1995; Dalfelt 1998; Orindi and Murray 2005).

Even without the anticipated climate change the dryland households are becoming more vulnerable as a result of various processes, such as impacts on market prices of agricultural commodities that make profits lower and operational costs higher. As rural villages often can be perceived as local micro-economies with internal price levels affected by poor connections to the outside, many village households are unable to get sufficient value for their produce. Such households have then to practice semi-subsistence agriculture or pastoralism, producing a small surplus in good years to sell and barter for needed goods and services. With increasing vulnerability over the years the households will have to liquidate more and more of their important assets. As the damage in monetary terms from climate variability and extremes in the developing countries increases, the level of losses appears to be more or less in constant proportion to an increase in national wealth. It also appears that the strength and forces that drive the cycle of poverty and environmental degradation are overwhelming in relation to the magnitude of resources that can be deployed against them (Burton 2001).

### 2.1.2. Desertification in the Sudan context

Arid and semi-arid ecozones constitute some 80% of the total land area of Sudan. The deserts and semi-deserts, which constitute some two thirds of the land area of the above mentioned ecozones, receives less than 300 mm of rain per year, while the remaining part or the low-rainfall savanna receive annually some 300 – 900 mm of rain. The remaining 20% of the land area comprises the high rainfall savanna, floodplains and mountain vegetation and has a precipitation ranging from 900 to 2000 mm in the extreme southwest. The Nile River and its tributaries form the most prominent physiographic feature in Sudan that has played an active part in the soil and vegetation formation processes along the total 9000 km of water course length within the country (MEPH/HCENR 2003).

The Sudanese Higher Council for Environment and Natural Resources (HCENR), established in 1992, coordinated the preparation of the first national communication as a climate change strategy response to the United Nations Framework Convention on Climate Change (UNFCCC). The authors used various locally adapted international climate change modelling tools to be able to forecast the climate change impacts on Sudan. The anticipated impacts for the Sudanese drylands can be summarized as follows (MEPH/HCENR 2003; Orindi and Murray 2005):

- Decreased rainfall, increased temperatures and evaporation;
- Frequent drought spells leading to severe water shortage;
- Changes in planting dates of annual crops;
- Increased insect infestations due to changes in temperature and humidity;
- Deceases in forest and cultivation areas due to land degradation;
- Decline in crop and gum arabic yields;
- Increased risk of food shortage and famine;
- Reduction in ecosystem integrity and decline in biodiversity;
- Increased potential of malaria transmission and the subsequent burden on the country's health care system.

The long-term meteorological trends have been studied in Sudan by, for instance, Davies and Alredaisy (1995), Mohamed (1998) and Elagib and Mansell (2000). The studies concluded that there has been a clear decrease in rainfall over the long-term by up to 30 – 40% in some areas, but there are annual precipitation variations which are larger than any decreasing trends. Elagib and Mansell (2000) found that, particularly for the weather data sets analyzed from Dongola, Shambat and El Fasher, respectively, it appeared that the highest temperature is reached during the autumn season (October), while the lowest temperatures of the growth period are in the summer months. This has implications for the agricultural sector, as the autumn season is important for crop growing.

The drop in crop productivity of sorghum and millet cultivated on rainfed lands of North Kordofan is forecasted to be 13 – 82 % and 20 – 76% respectively, while the drop in the same area for gum arabic production is forecasted to be in the range 25 – 35% by the projected scenario years of 2030 and 2060 (MEPH/HCENR 2003; Orindi and Murray 2005). Planning of mitigating strategies would therefore be needed, but so far the Sudanese development plans have mostly stressed the importance of increased agricultural production rather than tackling the balance between natural resource management and agricultural development. As a result, Sudan's natural resources have been neglected and are seriously degraded by destructive agricultural activities and indigenous tree cutting for firewood and charcoal making (Salih 2000).

The water resources and irrigation strategies in Sudan are primarily directed towards an expansion of irrigated agriculture in the country, and water is anticipated as the main constraint for this activity. The National Water Policy of Sudan (1999) recognizes, however, combatting desertification and drought and flood mitigation as key issues and calls for watershed management and environmental assessments and management to keep the water resources at a sustainable level. The importance of forests in watershed management is also emphasized, since the loss of tree cover has led to increased sedimentation and thus to a loss of storage capacity in irrigation dams (Salih 2000; MEPH/HCENR 2003; Orindi and Murray 2005).

The official figure for the population density in Sudan is only 12 persons/ $km^2$. However, a revision of the population density figure to account for the actual cultivable lands changes the population density to a much higher figure of 370 persons/ $km^2$ for the lands presently cultivated along the Nile. Further, approximately half of the total population is estimated to live on just 15% of the total land area. During recent years epidemic diseases have had a serious impact on the population. The most common diseases are malaria, diarrhoea, and dysentery. The diseases are expected to have considerable long-term socio-economic consequences for Sudan (Salih 2000; MEPH/HCENR 2003).

In constrast to the earlier emphasis on irrigation schemes during the last two decades Sudan has focused the agricultural production on large-scale rainfed agricultural activities which aim at increased production through a spatial expansion of the cultivated area. Per unit yields of all crops have steadily been decreasing and lie currently far below the genetic potential of the respective crops. Factors contributing to the low yields are losses in soil fertility, the rainfall variability and some increases in temperature (Ayoub 1999; WB 2003). The large-scale expansion of agriculture has been at the expense of trees and other woody vegetation, creating conditions which are not anymore suitable for sustainable agricultural production (El Naageb and Bromley 2002). Crop prices have during the last years been much higher than any potential income from natural acacia forests, and thereby farming has out-competed the other land-use options from large tracts of land. Pressures on forest resources are also high due to the fact that 75% of all energy used in the country is from firewood or charcoal. According to Ahmed and West (1996), desertification became in the early 1990s also observable in the Rahad Scheme area at the Blue Nile, which had until then been spared from such degradation. The reason for this expanded desertification is a total neglect of the agriculture sector to incorporate other land use alternatives in the farming system; this shows a lack of proper land use policies (Ayoub 1998).

In Sudan, the major causes of soil degradation have been ranked as overgrazing, wrong agricultural practices such as mechanised rain-fed agriculture, excessive tree harvesting for firewood and charcoal supplies, and over-exploitation of the vegetation for domestic uses. Overgrazing by livestock affects approximately 30 million ha, mostly in the arid zone, causing widespread wind erosion (FAO 1985; Ayoub 1998). Further, overgrazing, deforestation, and overexploitation of the vegetation cause both sheet and gully erosion in the semi-arid zone. A high population imbalance in some areas further aggravates the situation. Studies show that the dominant *Acacia senegal* tree has not been able to regenerate successfully due to goat grazing in many of its natural habitats. Tree seeds and seedlings are also otherwise vulnerable to destruction due to insects, lack of water and high soil temperatures (Hussein 1991). The permanent settlement of semi-nomadic or nomadic ethnic groups with their livestock has had a severe impact on the native vegetation. Large herds of livestock have destroyed the possibility of the vegetation to regenerate (Seif ElDin and Obeid 1970). Without human or livestock interference the native acacias and prosopis are well adapted to changes in climate conditions (Laxén 1990; Sprugel, 1991; Schlesinger and Gramenopoulos 1996).

In a short time period the shrinkaging or expansion of green vegetation can change the landscape depending on the annual rainfall (Ayoub 1998; Tsintikidis et al. 1999; Larsson 2002).

### 2.2. Prosopis as a resource and as a means to mitigate desertification

#### 2.2.1. Historical overview of the prosopis introduction in Sudan

Different species of prosopis have for hundreds of years been used in various parts of South and Central America as well as in the southern parts of North America in arid and semi-arid environments as the main plant resource for shelter, fuelwood and fodder in areas where few other woody species can grow. Various written sources ranging from notes prepared by early Spanish soldiers, explorers and priests to later studies of Native American cultural traditions bear witness of long historical utilization of these species. Written records are supported by archaeological and plant genetic studies from the region (Felger 1977). Records also show that South American prosopis trees were first introduced by colonial administrators and seamen into West Africa in 1822, and since the 1880s, repeatedly to western and northern Africa, as well as to southern Africa (Diagne 1996). Prosopis also spread westward from South America to various places on the Asian mainland, to many Pacific islands, and to Australia (Harsh et al. 1996; Pasiecznik et al. 2001).

A prosopis species, identified as *Prosopis juliflora* (Swartz) DC., was introduced in 1917 to Sudan simultaneously from both Egypt and South Africa by R.E. Massey, who worked at the Egyptian Department of Agriculture in Giza. The imported seeds were sown at Shambat, Khartoum North, from where prosopis has later been spread by humans to other places in Sudan. In 1928, another plantation was established near the present Khartoum airport. The naturalised prosopis around these plantations was observed to grow best on crests of sand dunes and, therefore, the following plantations in the 1930s were made to stabilize sand dunes southwest of Khartoum. After this, prosopis seeds were distributed in various directions; to Sennar and Fawwar near the Gezira Agricultural Irrigation Scheme, to Port Sudan, and to areas north of Khartoum along the Nile. In the 1960s prosopis was introduced in the Khartoum greenbelt at Soba, the Kassala greenbelt, the Gush, and the New Halfa Agricultural Irrigation Scheme in Kassala State. In those days the species was confused with *P. chilensis*; this appears to still be a common confusion in many parts of the Sudano-Sahelian region. During the 1980s many other species of prosopis were tested in trials in Sudan, but *P. juliflora* is currently stated to be the species common over large parts of Sudan (Bari 1986; ElFadl 1997; Pasiecznik et al. 2001). In this study the name prosopis will refer to *P. juliflora* if not indicated otherwise.

The main reasons for introducing different species of the genus *Prosopis* around the world have been combating desertification and utilization of a fast-growing fuelwood and fodder species that thrives in harsh arid and semi-arid conditions. All over the tropics and sub-tropics there are reports of their performance in terms of these purposes (Harsh et al. 1996; Diagne 1996; Pasiecznik et al. 2001; Kaushik and Kumar, 2003). In Sudan prosopis has been useful in combating desertification by stopping the sand dune or sheet sand encroachment on sandy soils (Mustafa 1986; Bari 1986; Bossard 1989; ElFadl 1997; Mutsambiwa et al. 1998; Salih 1998; ElFadl and Luukkanen 2003). However, there exist two diametrically opposing opinions on the usefulness of prosopis in Sudan. The first opinion is the above-stated usefulness in combating desertification, and this is the opinion of many forestry professionals and particularly the rural poor, while the second considers the tree as an alien invasive species which is a noxious weed in agricultural areas. This second opinion is mainly the one of the agricultural sector (ElFadl 1997; Pasiecznik et al. 2001). This issue will be further elaborated later in the text.

### 2.2.2. Presentation of *Prosopis juliflora*

The genus *Prosopis* Linnaeus emend. Burkhart was systematically described and organized by Burkhart (1976) into five sections that together contain 44 species and a large number of varieties. The genus belongs to the family Leguminosae (Fabaceae), sub-family Mimosoideae. *P. juliflora* belongs to section Algarobia that has six series; specifically it belongs to the series Chilensis that contain eleven species and many varieties. *P. juliflora* is particularly closely connected to *P. pallida,* and it is customary to refer to the two species as the *P. juliflora – P. pallida* complex, as the genetic variation is large and hybridization between these two species and some other species in the series is common. The *P. juliflora – P. pallida* complex contains the only two species that are truly tropical in their requirements and have a low tolerance for temperatures below zero degrees Celsius (ElFadl 1997; Pasiecznik et al. 2001; Räsänen 2002).

According to Kumar et al. (1998) the genetic variation of *P. juliflora* is high for all characters tested in the species. Major variation has been observed within progenies from a single parent tree and substantial variation has also been found at the individual tree and provenance level. Hybridisation is common between most prosopis species within any given section of the genus (Pasiecznik et al. 2001; Siddig 1986; Bari 1986).

Normally the tree can reach a maximum height of 3 – 13 m depending on the water availability at the site, but under special favourable conditions some individual trees can reach up to 20 m. *P. juliflora* landraces often have multi-stemmed and prostate habits with long branches and a crown that even touches the ground. The tree bole is usually short, crooked and twisted. Erect forms also exist, but normally it is difficult to find boles that have straight timber parts for more than 1 – 2 m without branches or forks. The crown is usually wider than the tree is high. The bark is brownish, fibrous, and increasingly furrowed on more mature trees. The root system has under normal circumstances two kinds of roots: (a) a deep vertical root system made up of normally one or two main tap roots which may further divide at lower depths, and (b) a lateral root system, which extends horizontally in all directions just below the soil surface. The deep root system anchors the tree and brings up groundwater to the tree, while the lateral roots collect rain and other surface water as well as nutrients just below the soil surface. The lateral roots have two types of secondary roots. One type grows upward almost to the soil surface and sometimes establishes new stems by sprouting. Another type of secondary roots grow down and transport water and nutrients from deeper layers. The tap roots can reach a depth of 20 – 25 m, but trees have been found that can reach substantially deeper. In case of a hard pan, the roots first grow down to the hard pan, and then, where it is possible to penetrate it, further down (Bossard 1989; Pasiecznik et al. 2001)

The thorns of prosopis vary much in appearance and can, for instance, be either paired or solitary or both on the same branch. Thorns are only produced on new branches and tend to be largest on strong basal shoots, while they become absent on larger stems due to dropping of the thorns or wood growth incorporating them. The thorns vary much in size also between tree individuals, from large, thick and strong thorns of up to 7.5 cm in length to small and weak ones of less than 0.5 cm in length (Pasiecznik et al. 2001).

The prosopis flowers are hermaphroditic and insect-pollinated. The flowering dates vary from site to site, but within each site the flowering is synchronized and probably photoperiodically controlled. The blooming is relatively constant and lasts usually for some two weeks, while it takes three months for the pods to mature. The pods can each contain up to 30 seeds that are embedded in the exocarp, a fleshy mesocarp, and endocarp segments for each individual seed. Flower bud production in the Soba area of Sudan starts normally in October, continues to reach its peak in

February and decreases until the end of April. In a trial conducted at Soba in 1981 - 82 the pod production was, on average, only 0.77 kg/tree and ranged between 307 and 1,344 kg/ha for 400 trees/ha. The rainfall for the trial period from March 1981 to March 1982 was exceptionally low for the site, or only 105 mm. This is a little lower than the current average rainfall in the Shendi area of River Nile State (cf. MEPH/HCENR 2003). The flower and fruit production can be considered as a continuous yield during the critical dry season period from December to June. The flowers and fruits are important as forage for the livestock during the peak dry season. The pods ripen during this period, but require some additional water to develop in more abundant amounts (Siddig 1986).

The *P. juliflora – P. pallida* complex species have in South and Central America a distribution from Peru in the south to southern Mexico in the north, with introductions also made on the Caribbean islands. In Africa their distribution covers currently of the most arid and semi-arid regions of the continent, with smaller patches of sites in the northern African region where the climate can be too cold during parts of the year for them to become fully acclimatized. In Asia they can be found in the Middle East including the southern parts of the Arabian Peninsula and in Pakistan and India, with small patches in Thailand and the Philippines. They can also be found on several Pacific Islands and in the northern and central parts of Australia (Pasiecznik et al. 2001).

Prosopis grows on all soil types from pure sand to heavy clays and even on stony soils, but deep loose sand soils are preferred. The above-ground growth is stunted if the root system is blocked for any reason (Mustafa 1986; Salih 1998;). If the tree cannot find proper hold in shallow hard soil, wind throws can occur. They may also occur in case the site is water-logged and the oxygen content of the soil is low. The tree has proven itself well-adapted to various altitudes where it has been introduced. Soil properties can sometimes constrain its growth; for instance, a sufficient level of phosphorus is needed for efficient nitrogen-fixation. There is a strong correlation between P and N contents in the soil and those in prosopis leaves (Diagne 1996; Muthaiya and Felker 1997). Otherwise alkalinity, salinity and water deficit will not limit its growth much. In alkaline soils the lack of micronutrients may have a limiting growth impact (Khanzada et al. 1998; Pasiecznik et al. 2001; Kaushik and Kumar 2003). Near Port Sudan prosopis grows along large parts of the very shoreline of the highly saline Red Sea (ElSiddig et al. 1998; personal observation).

Regarding the water requirements prosopis has a wide range of tolerance. It extends from areas with an annual rainfall of only 50 mm to high-rainfall areas with over 1,500 mm of precipitation. If the root system is able to find water during drought, prosopis will stay in green leaf throughout the dry season. The average optimum temperature for prosopis is from 20 – 32 $^{o}$C, but the whole temperature range is from about -1.5 to over 50 $^{o}$C. It further tolerates soil temperatures in full sun light as high as 70 $^{o}$C (ElFadl 1997; Pasiecznik et al. 2001). In case the above-ground part is destroyed, for instance, by frost, drought or cutting, there are dormant buds some 10 – 15 cm under the ground surface from which the tree can sprout again (Räsänen 2002).

### 2.2.3. Utilization of prosopis

Prosopis is able to improve the soil in which it is growing by means of biological nitrogen fixation, leaf litter accumulation, nutrient pumping from deeper soil layers, loosening of a hard soil structure, stabilizing of loose sands, and an increase of the fauna above and below the ground (Kaushik and Kumar 2003). Its nitrogen fixation ability has been found to be mainly limited to young seedlings in the same way as in *Acacia senegal* (Robertson 1994; Aiazzi et al. 1995; Aiazzi et al. 1996; Geesing et al. 2000). Diagne (1996) calculated that one-year-old seedlings planted with a density of 650 stems/ha had fixed nitrogen about 20-25 kg/ha. Significant nitrogen accumulation occurs in all soil layers under prosopis (Mazzarino et al. 1991; ElFadl 1997; Muthaiya and Felker 1997). Geesing et al. (2000) concluded that *P. glandulosa* builds up the soil carbon with an amount estimated to be 35-38 kg/ha/a. Prosopis is able to create “islands of fertility” on land with poor soils, and after several years of soil improvement other species will be able to gradually take over, as prosopis looses its competitive advantage (Archer 1995). Prosopis has been proven to reduce both the alkalinity and the salinity where it grows on sites, on which, for instance, *Acacia nilotica* just accumulates salts in its root system to an extent that limits tree growth (Khanzada et al. 1998). Prosopis has been able to rehabilitate former industrial sites polluted by heavy metals (Mustafa 1986; Mutsambiwa et al. 1998; Pasiecznik et al. 2001).

Even though prosopis trees compete with grasses for nutrients and water and have extensive root mats in savannas, the grasses are often taller and greener under the trees than they are when they stand alone in open areas. The physical benefits of shade appear to be supplemented by the enrichment of the soil from tree litter and animal droppings and urine, which is accumulating when the livestock is foraging and resting under the prosopis trees (Pereira, 1989). A study by Connin et al. (1997) conducted in New Mexico, USA, indicated that a replacement of semi-arid grasslands by the woody shrub *Prosopis glandulosa* var. *torreyana* due to overgrazing in the area had affected the SOM accumulation under the prosopis shrubs through their larger root biomass, larger litter production and nutrient cycling. Similar results were also obtained by Kaur et al. (2002) from trials with six-year-old *Prosopis juliflora*, in semi-arid sodic savanna soils in north-western India. The above-ground plant biomass in the latter case amounts to 35.8 t/ha, while the groundcover and below-ground biomass (ground litter, roots and grasses) totalled 13.4 t/ha.

The prosopis increases the amount of soil organic matter (SOM) in the soil directly and thereby positively influences the potential of the soil to absorb soil moisture, which leads to sustainable soil fertility. Further, the soil moisture controls the soil carbon and nitrogen cycles both directly and indirectly: directly, it impacts on decomposition, leaching, and plant nutrient and water uptake; indirectly, it impacts through influences on plant growth and on the amount and composition of plant residues (Porporato et al. 2000; Kimble et al. 2002; Singh and Rathod, 2002).

Due to its bushy growth habit with branches down to the ground prosopis is commonly used for shelterbelts around the world. It provides shade and thereby reduces the near-ground temperature, which is particularly important during periods of active plant growth (Muthaiya and Felker 1997; Mutsambiwa et al. 1998;). In the Tendelti area of White Nile State in Sudan, ElFadl (1997) measured a $2^{o}$C decrease in air temperature under prosopis; this reduced the evapotranspiration while increasing the relative humidity. The same researcher also measured in an open space inside a 2.5 - 4 m high bushy prosopis stand without overarching crowns temperatures a few degrees higher than those found outside the stand; this was attributed to standing air. The ability of prosopis to stabilize sand dunes with its widespread fine roots has been documented all over the tropics (FAO, 1985; Mustafa, 1986; Mazzarino et al. 1991; Mutsambiwa et al. 1998; Pasiecznik et al. 2001; Kaushik and Kumar, 2003).

The wood obtained from prosopis varieties of the section Algarobia in South and Central America as well as southern North America has many recorded uses. However, the colonial administrators of the $19^{th}$ and $20^{th}$ centuries preferred to bring with them to Africa and other places in the world such prosopis varieties that were more suitable for combating desertification or production of fuelwood and fodder than for producing, for instance, high quality timber or human food (Diagne 1996; Harsh et al. 1996). The land races of prosopis introduced to Sudan have a more bushy, thorny, and crooked stem appearance than the American high-quality prosopis timber trees (Mutsambiwa et al. 1998; Pasiecznik et al. 2001). The American varieties of prosopis also have a higher sugar content and a less bitter taste in their pods than the prosopis naturalized in Sudan. In River Nile and

Northern States of Sudan it has been observed in shelterbelts and other places along the Nile where prosopis can use ground water that it can produce a straight and clear bole when managed properly (cf. Bristow, 1996; Mutsambiwa et al. 1998).

According to the Forests National Corporation staff in Shendi, there had been in the early 1990s, adjacent to Ed Damer town, a stand of old prosopis trees with diameters around 40 cm which had been cut to timber and further manufactured into furniture. The quality of the timber and the produced furniture had been excellent in the local forester's opinion. In Sudan the prosopis roundwood is normally used for poles of various sizes required for simple construction and tools, as the pieces of wood are mostly crooked and short. According to Pasiecznik et al. (2001) the wood has a durability, strength and hardiness comparable to or better than those characteristics in mahogany or teak.

Prosopis is an important source of household energy for millions of people in arid and semi-arid zones of the world. The wood burns evenly and hot, as it has a high density and a calorific value estimated at 4,220 kcal/kg in young trees (Khan et al. 1986) that increases as the trees mature. The wood burns well even when fresh and green, although the calorific value is then reduced due to the moisture content. Approximately 3-6 kg of prosopis wood is required to produce one kilogram of charcoal, depending on the production method (Otsamo 1993). The American charcoal of prosopis (commonly known as mesquite) is recognized for its pleasant smell and taste, which makes it preferred for barbeques. However, the prosopis wood in Sudan is not known for such pleasant smell and taste, even if it is sold widely as fuelwood and charcoal. In Sudan, *Acacia seyal* charcoal is preferred when good smell and taste is required from charcoal (ElSiddig et al. 1998).

Prosopis pods are used in Sudan mainly for livestock fodder, which is normally browsed directly from the trees. In the Tokar delta of Red Sea Province prosopis pods have been collected on a large scale and ground in a mill for livestock feed[2]. Individual households everywhere in Sudan where prosopis is growing also collect the pods, which are directly given to fenced-in livestock as fodder (ElSiddig et al. 1998).

Dead and living fences made from prosopis are effective against livestock due to the thorniness and multi-stemmed bushy habit of the species. In Sudan the shade from prosopis trees for humans and livestock is widely appreciated. Plantations of prosopis have been established to stabilize sand dunes or loosen up sand soils (Bristow 1996; Mutsambiwa et al. 1998;). Degraded sites are also naturally invaded by prosopis in many places in the tropics and sub-tropics (Pasiecznik et al. 2001).

No new plantations or shelterbelts with prosopis have been established by Sudanese forestry professionals after the enforcement of the Presidential Decree on eradication of the species in 1995, and also the extension on silvicultural and management practices for prosopis has been prohibited. Currently prosopis is widely naturalized in Sudan and all its expansion and regeneration is the result of natural invasion. The seed dispersal is now mostly effected by livestock; their digestive tract gives the seeds the necessary pre-treatment for germination and the seeds are dispersed through animal droppings. Due to the eradication decree the prosopis resources were left out of the 1995 national forest inventory of the central and northern parts of Sudan. The reason for this was that the species was considered a weed and supposed to become eradicated quickly (Gorashi 2001). Even the Sudan country presentation in the document Forestry Outlook Study for Africa (FOSA) does not mention prosopis anywhere in the report, although in many areas of the country most of the fuelwood used consists of prosopis (cf. Salih 2000).

[2] Personal communication with Prof. Ahmed A. Salih, Director of the Forestry Research Centre in Soba.

## 2.3. The usefulness of prosopis versus its status as a weed

The issue of the usefulness of different prosopis species versus their status as weeds is a matter of hot debate around the world. Some 15 prosopis species are weedy in their native range and elsewhere where they have been introduced. *P. juliflora* had until 2000 been proclaimed weedy in its native range in Colombia and Venezuela and as an alien invasive species in Australia, the Carribbean, Eritrea, India, Iraq, Pakistan, South Africa, Sudan and the western African islands (Pasiecznik et a. 2001). Since then several other countries, for instance, in the Middle East and in Africa, including several neighbours to Sudan, have now got their eyes open for the invasiveness of prosopis. As a result prosopis species are defined as weeds over millions of square kilometres all over the arid and semi-arid lands where they are stated to drastically reduce the cover of forage plants and threaten crop cultivation and grazing. Humans and livestock both appear to have contributed to this invasion of prosopis, as indicated by the fact that these lands tend to have an imbalance in nutrients and fertility or show degradation in other ways (Habte 2000; Felker 2003 and 2004).

Generally speaking it can be concluded that, of all the introduced plant species around the world, only a fraction has eventually established viable populations and even a smaller fraction has become invasive. Most of the introduced plant species worldwide have either found their place without causing much harm or been clearly beneficial to the new areas. Useful introductions include almost all major global food crops (Perrings et al. 2005). It is commonly assumed that the spreading of an invasive species is due to a lack of natural predators and diseases in the new environment. This may be occasionally true, but the situation is more complex and involves also the specific relationships these new species develop with their surroundings over a longer time period. Further, it involves a new equilibrium between a species and its environment which eventually will stabilize the population. This balance may develop quickly, but sometimes it takes a long time and still sometimes it happens that indigenous species are completely out-competed and even may become extinct. For prosopis the last option cannot be confirmed. In relation to prosopis, both negative and positive changes in the populations of other species have been reported, but often the changes in soil fertility, browsing pressure and micro-climate caused by other factors cannot be separated from those depending on prosopis (Habte 2000; Geesing et al. 2004; Wittenberg et al. 2005).

Prevention is a first priority option in the management of invasive prosopis, and the success is then measured in terms of invasions that did not happen and the costs involved. The next option is then to organize an early detection system, which has a vital role in the reduction of costs from invasion. In case an early detection fails and prosopis becomes established in wrong places, then eradication will often cease to be a viable economic option. Prosopis is not always invasive in an environment, and therefore it is useful to have sufficient knowledge from other similar sites to decide on the intervention intensity in any given situation. A further option would be the technical and financial planning and the actual management of prosopis control, as a specific project. In case it is known that prosopis will create higher costs than benefits and the costs would be high also in monetary terms, eradication should be considered as an alternative. This should be attempted only if it has a chance to be successful. If eradication is not feasible, then the next step is containment of prosopis in the infested area by monitoring that it does not spread to a larger area (Geesing et al. 2004; Wittenberg et al. 2005).

Eradication of prosopis has been tried out in many places around the world. In most cases the attempt has not been very successful, and in some cases it has even made the situation worse (Habte 2000; Pasiecznik et al. 2001; Geesing et al. 2004). The size of the trees is an important factor when determining the options. With young seedlings it may be enough to spray them with herbicides or just burn them by using containerized gas equipment. Older trees need to be mechanically felled and cleared away before digging up the stumps with an excavator or human labour. The stumps need to be lifted up from the soil so that 30 cm of the root system below the ground level is cleared away, as the root collar has dormant buds which would otherwise sprout. Fairly successful killing of stumps has also been achieved through soaking the stumps in kerosene and burning them on the spot without lifting. Biological control has been tried in some cases, as there are several shoot borer beetles which are able to at least weaken the tree. A successful option to control prosopis is also to promote its heavy utilization (Felker 2003, 2004; Geesing et al. 2004).

The term “invasive alien species” used, for instance, for prosopis, contains the two heavily negatively loaded words “invasive” and “alien”, which easily leads to considering the situation from the negative aspects only (Ehrenfeld, 2000). A deeper understanding of the situation also requires information on possible beneficial aspects of an introduced tree species. Costs are usually fairly easy to estimate, but benefits are often hard to capture in monetary terms. Therefore a site-specific and objective assessment may be required to tailor-make interactions in accordance with the needs, based on a realistic understanding of the situation. In many of the cases where a species is problematic it may be that there are also other reasons behind an already ongoing negative development and the new invasive species is in fact alleviating some of the problems (Archer 1995; Habte 2000; Geesing et al. 2004; Nkando 2004). For instance, Varshney (1996) concludes that, although prosopis is an alien invasive species on the semi-arid and arid lands in India, it still is more beneficial for the local population and the environment than a situation without this tree species.

### 2.4. The Sudanese agricultural sector and prosopis

Sudan has a land area of 2.5 million $km^2$ and a population of 31.7 million inhabitants (WB 2003), and a high agricultural potential, particularly where irrigation is possible. However, there is a scarcity of water in many parts of Sudan, which is a serious constraint to an expansion of the sector. Despite water constraints the agriculture sector has been able to keep up the role as the main source of employment and household income in the rural areas, where about 65% of the population in Sudan live. In 2002, the cultivated arable land area was 17.2 million ha, which is about 20% of the potential arable land. The agricultural resource base already in use in Sudan is one of the largest in Africa. This resource has an export potential and includes, apart from the cropland, also pastures for livestock, forests, swampland resources, and fish resources in the Nile and the Red Sea (Donovan 1996; Mohamed 2002).

There are three main farming systems in Sudan: (a) irrigated agriculture, (b) large-scale mechanised rainfed agriculture, and (c) traditional small-scale rainfed agriculture. In the official statistics of the 1990s, the irrigated agriculture accounted annually, on average, for 21.1% of the value of the total agricultural production; the large-scale mechanised rainfed farming accounted for 6.3%; and the traditional rainfed farming for 12.5%. The value of livestock production during the same time period accounted for 47%, while forestry and fishery accounted for the remaining 13.1% of the total agricultural production (WB 2003).

The large-scale mechanised tractor-based rainfed farming has during the last one and a half decade expanded considerably. Unfortunately, there has been a low level of inputs to this sector in terms of fertilizers, water, pesticides and plant breeding, and therefore the productivity has been low. This farming system would need to intensify the productivity substantially per farmed land area unit in the future; instead the trend has been a decreasing one during this time period (Mohamed and Sanders 1998).

The era of large-scale irrigated agriculture in Sudan began almost a hundred years ago, along the Nile, under the British colonial rule. Currently there is 1.7 – 2.1 million ha of land suitable for irrigated agriculture within the Nile Basin, in Northern, River Nile, Khartoum, Gezira, Sennar, Kassala, Blue Nile and White Nile States. The first and largest of the irrigation schemes, established in 1925, is the Gezira irrigation scheme with an irrigated area of 882,000 ha (WB 2000; Guvele 2001). Three other large-scale irrigation schemes (Suki, Rahad and New Halfa) have together 420,000 ha of cropland under irrigation (WB 2003). Apart from the four major schemes there are several tens of small and medium size schemes from Kosti in White Nile in the south to Dongola in Northern State in the north. During the last decades there has been substantial economic reforming in the irrigation sub-sector, and the irrigation schemes have been forced by the government to function as self-financed and administratively decentralized units, which have become more participatory in water management through the introduction of water user associations (ElAwad 2000). Many of the irrigation schemes were, however, ill prepared for these reforms, and in most schemes there are now financial difficulties that make additional governmental financial support actions necessary. Indicative for problems in the schemes is now also the fact that several of them are heavily invaded by prosopis and their managements are highly critical towards this tree (cf. Vink 1987). The New Halfa Irrigation Scheme was one of the most heavily invaded areas in Sudan by the start of the new millennium (Mageed et al. 2001).

## 2.5. Achievement of sustainable development for dryland Africa

### 2.5.1. Sustainable development and valuation of non-market values

Today forest and environmental policies are internationally discussed within the framework of the United Nations Forum on Forests (UNFF), which among other issues strives to develop an over-arching international instrument for sustainable forest management (SFM). The SFM concept constitutes currently a prerequisite for channelling development assistance to the forestry sector. The concept (framework) emphasizes development and implementation of strategies that acknowledge the full range of forest values and functions, integration of local livelihood needs, as well as the participation of local communities and other civil society stakeholders (Virtanen and Palmujoki 2002; MfFA 2005).

The UNCED-defined term “sustainable development” has been under constant revision since the conference on the environment held in 1992. After the conference, social and economic aspects were included and by the mid-1990s the concept focused mainly on poverty reduction. Then it was again revised so as to define sustainability as a balance between environmental, economic and social dimensions, still with strong emphasis on poverty reduction. During the last few years the concept has become even more complex, although also more concrete; it now focuses on market-based sustainability in an unequal world. Thus all goods and services in all sectors (environmental, social, cultural and economic sectors) should be evaluated in qualitative and quantitative terms to be able to make decisions on their respective importance. The quantitative assessment includes the development of indicators for sustainable development. For the environmental issues the indicators are policy relevance, analytical soundness and measurability. Measurability is based on a need to develop economic tools for valuating everything for use and non-use values. This means that environmental, ecological and social non-market goods and services need to be monetised to balance the economy-based decision-making. A clear role for environmental economics in the monitoring of sustainable development has thereby been identified (IUCN/WB 2004; IUCN and PROFOR 2004; Giovannini and Linster 2005).

According to Convery (1995) environmental economics could support sustainable development in Africa through, for instance, the following:

(a) Identifying and estimating large environment-related losses to the economy and establishing their linkages with economic development;
(b) Prioritizing issues in the National Environmental Action Plans (NEAP);
(c) Estimating the costs and benefits of various environment-related options;
(d) Factoring in environment considerations into sectoral policies;
(e) Encouraging the emergence of real market prices, their systematic collection, analysis and use in allocating scarce resources.

Soil degradation is a major threat to the livelihoods of the rural poor who are likely to live in degraded and fragile areas (Pagiola 1999). Such risks have always been part of the rural livelihoods, and therefore complex strategies to master ecological and seasonal variations in environmentally risk-prone areas have been developed. These strategies are increasingly being caught up by global processes of change over which the rural poor have neither control nor information necessary to anticipate how they will be affected. Furthermore, programmes of structural economic reform, privatization and decentralization (today also in the form of national Poverty Reduction Strategy Papers, PRSPs), interact with the local processes that shape people's lives. One step further, environmental resource management is becoming increasingly global as international conventions, laws, and non-binding instruments and structures seek to regulate the terms of people's access to natural resources. The agriculture sector alone is not anymore able to generate sufficient rural wealth. A broader multi-sector approach to rural development is needed that builds on local empowerment, risk mitigation and social protection (Baumann 2002; Campbell and Luckert 2002). The planning and valuating of natural resources in developing countries aiming at sustainable development will encounter various economic market failures which need consideration and mitigation in the process (Kirkpatrick and Weiss 1996; Brent, 1998).

Many forest valuation studies prepared for developing countries have, until recently, been conducted in isolation from forest policy and management. Therefore, one of the greatest challenges for the future is to solve how to close this gap between research on the one hand and practical management, investment decisions and policy development on the other. Practical managers and decision-makers in developing countries will be unlikely to seriously consider environmental economic values which cannot properly show how and for whom these have been captured, when these managers and decision-makers simultaneously have to support poor rural people trying to satisfy their immediate basic needs. The focus in developing countries has also tended to be on direct use values of particularly non-timber forest products, which have been thought to suffice to balance timber harvesting. On the other hand, the focus in developed countries has been on recreational and existence values held by urban consumers, and therefore the valuation techniques developed in industrialized countries are often less useful in a developing country context (Bishop 1999). What is really needed is valuation that determines holistically the situation in a specific location under study. Only in this way the environmental values can be compared with each other and with other economic activities in the area (Kengen 1997; Abeygunawardena et al. 1999).

### 2.5.2. Bioinvasions and ecosystem services

Biological invasions are often side-effects of problems within markets, institutions and property rights that influence economic decisions and are caused by intended or unintended economic activities. An economic approach to solving the problem strives first to identify the reasons and consequences and then to select suitable options for addressing the problem. The options available include usually, apart from the preventive measures, also the options of eradication, containment, mitigation and adaptation. The first stage in the assessment is to identify all the impacts of the invasive alien species. Ecological impacts are often difficult and cumbersome to assess in economic terms, but once identified and quantified they may be as significant as the concrete economic ones. An economic and ecological assessment of benefits and costs of an alien invasive species is normally attempted using cost-benefit analysis (CBA), where benefits and costs accumulating over a time period are discounted towards net present values, so as to enable a comparison of the scale of impact (Perrings et al. 2005). However, due to the complex processes involved, most CBA exercises in developing countries are carried out in a somewhat reduced form. Most studies cover only shorter time periods, such as one year, due to uncertainties and fluctuations in terms of prices, inflation, the productivity as affected by drought, and many other similar factors that occur over longer periods (Kengen 1997; Bishop 1999; Boxall and Beckley 2002).

The term “biodiversity” is a term that appears easy to use and write, but so far nobody has been able to fully grasp all the complexity it contains and particularly how to really measure or valuate all its contents in a satisfactory way. The definition implies multiple layers of diversity: (a) the diversity among species, (b) the diversity within species among individuals, and (c) the cross-habitat diversity among populations, which leads to (d) a diversity in which all layers interact in ecosystem clusters with each other. Alternatively, biodiversity can encompass “inventory-style” definitions and “difference” definitions. The latter two types of definitions have their respective functions for different users and decision-making processes. The “difference” definition seems to be superior in capturing the biological and ecological understanding of biodiversity, while the interest among policy makers and the public is better raised by an inventory-style definition. It has so far been difficult to go deeper into the issue, as the term biodiversity refers to complexity which does not allow much reduction to simpler concepts. For measuring and valuation purposes one should thus not expect to find any single objective, pre-existent biological parameter; nor should one expect to be able to measure biodiversity in a precise manner (Williams 1999; Purvis and Hector 2000; Norton 2003).

The link between prosopis and biodiversity is mainly found at the ecosystem level: either (a) through the rehabilitation of an eroded and malfunctioning ecosystem, or (b) through the forming of a buffer zone between an area of higher biodiversity and an area under the threat of degradation or even desertification. Many researchers would further add here a third option in which prosopis invades ecosystems. This may be relevant, but there seems to be a tendency that the species usually becomes established on sites which to some extent already are degraded (cf. Habte 2003), thereby linking this option back to option (a) above. Functioning ecosystems contain multiple layers of interactions in clusters of services that can be divided into at least four groups, according to CBD (2003), coarsely described as follows:

- *Supporting services*, which are services that maintain the conditions for life on the Earth;
- *Regulating services*, which are benefits obtained from regulating ecosystem processes;
- *Provisioning services*, which are products obtained from ecosystems;
- *Cultural services*, which are non-material benefits obtained from ecosystems.

Ecosystems tend to be more stable and better functioning the more diverse the ecosystem is, as also shown in several field and laboratory studies. The reasons behind this fact can be divided into three types: (a) better distribution of risks reduces volatility; (b) different species compete with each other, and in case one species is lost another can replace it; and (c) the whole ecosystem is made up of various abundance struggles, which balance out the effects of each other (Tilman 2000; Purvis and Hector 2000). Humans have caused widespread changes in ecosystems through introductions of new species and the elimination of species in some habitats. The main human influences on ecosystems are derived from the human population growth, rural poverty, low farmland productivity, inequitable land-use systems, lack of property rights and tenure regimes, low environmental awareness, low level of agrotechnology, insufficient governmental support for subsistence farming, deficient rural infrastructure, and inadequate development overall. These changes alter ecosystem processes and change the resilience of ecosystems in reaction to environmental change. The degradation is now bouncing back with direct implications for services that humans derive from ecosystems. Therefore, if possible, the severe ecological and societal consequences that are caused by a decline in biodiversity should be minimized, so as to preserve options for future solutions to environmental problems (Myers 1995; Chapin et al. 2000; Vandermeer 2003).

### 2.5.3. Agricultural landscapes in arid and semi-arid ecozones

Landscapes are the results of the forces to which they have been exposed over time. Whether natural or managed, the physical landscapes are subjects to human interactions and natural processes. Agricultural landscapes show strong influences of both of these factors. Apart from these physical factors there is also a hidden landscape as well, which is the socio-economic constellation lying behind or alongside the physical landscape. The socio-economic constellation is found in the awareness of the human population inhabiting the landscapes and in the awareness of the authorities that govern the area (Vandermeer 2003)

The establishment of large irrigated agricultural schemes constitutes a major change in both the physical and the socio-economic constellation of a landscape (Vandermeer 2003). In Northern and River Nile States of Sudan in particular, irrigated agriculture has changed the living conditions completely for the human and livestock populations (Bashir 2000). What used to be rainfed agriculture and small field plots at the brink of the Nile has been expanded manifold in size and is now encompassing mainly dry-season large-scale cultivation in a belt on either side the Nile that is about three kilometres in width, with an additional zone 0.5 – 3 km in width consisting of villages, livestock grazing areas and fuelwood collection sites just outside the riverine irrigated cultivation zone. In some cases it is possible that the irrigation networks have enabled the maintaining of older landscapes, which otherwise would no more exist. Several new agricultural and horticultural crop species of even European or other temperate origin are now successfully grown in such irrigated fields during the cooler winter months of northern Sudan.

A farming system includes, apart from cultivated crops and the soil and its micro-organisms, also trees, shrubs, herbaceous plants, livestock, arthropods and other associated fauna; all interacting both positively and negatively with each other. Each of these above-mentioned factors have further components, which may each have different influences on the other major factors; particularly so in harsh arid or semi-arid marginal environments such as those prevailing in Sudan (Jiggins 1989; Marsner et al. 2001). Ecological interactions in this species assembly have thus vital consequences for the performance of the whole system (Rice 2003).

### 2.5.4. Role of forest environmental resources in rural household economies

According to Reddy and Chakravarty (1999), forest environmental resources significantly alleviate poverty in poorer households. Their results further indicated that restricting the access to forest resources is likely to increase the poverty. Policy measures that aim at improving the off-farm income may not be sufficient to cover losses to poor households resulting from restrictions on access to common property rights in the forests. Policy changes need to be carried out so that all population strata are involved in the process and heard, so as to generate awareness in the whole community on the role of forest resources in preventing environmental degradation.

Vedeld et al. (2004) conducted a meta-analysis of 54 scientific case studies based on research from various rural locations in the tropics and sub-tropics which had investigated the role of the environmental income in the total absolute household income. The results of the meta-analysis indicated that, in general, about 22% of the average rural absolute total income was derived from forest environmental income. The forest environmental income was particularly important from a coping and a safety net function point of view in the households' livelihood strategies. The same meta-analysis also indicated that about half of the forest environmental income was received in cash, but the share in cash declined with a higher relative forest environmental income. The absolute cash forest environmental income was at least as important in the poorer communities as in the wealthier ones.

Forest products frequently contribute more to poor households' non-monetary returns rather than to their cash income. One should also distinguish between the forest-dependent people's own subjective perceptions of well-being and those by other persons, for instance, a researcher in attempt to objectively form conclusions on externally defined, standardized indicators of welfare. Even among poor people a distinction between absolute and relative poverty is an important measure for the situation in an area. What really matters, for the households themselves, is their own subjective feeling of well-being. However, to be able to compare various populations and areas, one has also to have more objective information, and households may not always be precise about their own well-being either (cf. Angelsen and Wunder 2003). During the last few years in the rural Sudan, people have also increasingly started to compare their livelihood situation with that of other people living elsewhere, for instance, in cities. It is also likely that poverty has increased in Sudan and this has made households more aware of their own situation[3].

There are various types of poverty among rural households based on which assets the particular household lacks. A scarce asset can thus be related to natural resources, human resources, on-farm physical and financial resources, off-farm physical and financial resources, or social networks and institutions available for organizing and managing the scarce income opportunities. The respective type of asset shortage has an impact thus also on the environment - poverty links. The criterion for poverty in environment - poverty analyses should be the ability to make investments in resource improvements that either maintain or improve the quantity and quality of the resource base. A household below this level can be termed "investment poor" and differentiated from a "welfare poor" one. This latter term uses criteria based on income, consumption and nutrition levels benchmarked by some standard. Households above the "welfare poor" criteria may still be too poor or with some constraints on investments to engage themselves in soil conservation or farming practices that would allow them to avoid damage to their resource base or moving to fragile lands (Reardon and Vosti 1995).

Poor households initially often face difficulties in overcoming entry barriers and have high investment needs in such inputs and skills that eventually would lift them out of poverty (Zimmerman and Carter 2003). Commonly, poor households that strive to survive cannot look beyond the short term and will thus deal with the medium and long-term situation in a short-sighted way, which results in higher environmental externality costs than there were in the past. The most effective way of simultaneously reducing poverty and improving the resource base is to understand which assets the households are short of and to aim at supporting the accumulation of these assets first, either directly or indirectly (Reardon and Vosti 1995). This understanding is, however, constrained by the fact that these assets are often hard to value accurately, particularly in Africa,

[3] Personal observation while conducting household surveys.

where secondary markets are poorly developed and the assets generate highly variable returns on inputs (Barrett et al. 2001).

Where markets for credit and insurance are missing or thin, income diversification that includes also forest income sources is a good precaution for risks. This diversification is also important later on when the households are actually coping with severe income shocks, and needing cash, to buy, for instance, crop cultivation inputs, or for making long-term investments (Fisher 2004). Frequently the transaction costs are so high that it becomes worthwhile for a household to be self-sufficient in some particular product or service. There are also complementarities between livelihoods, such as the one between crop cultivation and livestock rearing which motivate income diversification (cf. Barrett et al. 2001).

Another, contrasting situation is the one of too high reliance on low-return activities, including many forest activities, which is likely to help the poor households to survive but not to overcome poverty. A more effective strategy to alleviate poverty would be to help a poor household to find other more gainful income opportunities. Such an alternative strategy would be to improve the markets for low-return forest products, to the effect that market prices would increase. A risk with this approach may be that then also wealthier households may be tempted to take over at least part of the income-generating activity (Dercon 1998; Woldenhanna and Oskam 2001; Fisher and Shively 2005).

## 3. THEORETICAL FRAMEWORK

### 3.1. Selection of the overall approach and the entry point for the valuation excercise

This present study is focused on solving of a real-world problem concerning how an invasive alien tree species should be economically perceived in an area. It is challenging to investigate, from an ecological (environmental) economic angle, complex natural systems that do not respect traditional scientific rules of repeatability or allow experimentation in the laboratory or even controlled conditions in the field. If our scientific methods are insufficient for solving an economic problem in the real world, we do not typically have the option of choosing another more easily resolvable problem. Often are such problems so complex that no single discipline alone is equipped to resolve them, and one needs to cross the artificial disciplinary and institutional boundaries. This allows the investigator to have more than one set of specific methodologies and to make the problem under study determine the necessary tools and disciplinary insights. This scientific approach is known as problem-based research (cf. Daly and Farley 2004; Farley et al. 2005), and it provides the core of how the present study has been outlined and evolving from the start of the research process.

This study aimed primarily at determining the overall benefits and social costs of prosopis at two representative sites in Sudan. There are three main optional analysis approaches for determining non-market goods and services for rural people in development country contexts. These options are: (a) development project assessments (including Total Economic Valuation, TEV-studies), (b) so called “green”-accounting assessments, and (c) household economic surveys (Veeman and Luckert 2002). As this study can be seen as a development project or investment activity for prosopis, the most rational option was here the alternative (a) above. Also simplified versions of (a) in the form of valuation of magnitudes of impact were relevant. However, (a) is also the most demanding option, which requires substantial amounts of relevant data collected or available for the work. As this was not the case at the outset of the work, there had to be a strategy for how data could be retrieved and two representative research sites selected. This chapter will stepwise first describe how data collection was accomplished and then elaborate more in-depth the framework for valuation.

In the past decade, with renewed international commitment to poverty reduction, there have been significant theoretical and practical advances in the way poverty - environment linkages are included in the mainstream development policy. Rural poor people are particularly dependent on natural resources and ecosystem services for their livelihood. Increasingly the rural poor live, on the one hand, in areas of high ecological and environmental vulnerability, and on the other, with relatively low levels of resource productivity available for them. The position of the poor in this marginal situation, as well as the low level of access rights over productive natural resources, is a major factor contributing to rural poverty. Rural poverty has been accepted as both a major cause of and a result from degradation of soils, vegetation, forests, water, and natural habitats (Pagiola 1999). Dwindling forests and related losses in biodiversity are depriving people of valuable assets, such as fuelwood, food, and medicine. An estimation of the values and income opportunities that forests can provide for rural households is a key to understanding the role of forests in rural livelihoods in a given area (Baumann 2002; Campbell and Luckert 2002).

There was therefore a need to have a good understanding of how household members in the selected framed areas were thinking when making their decisions. The choice of household economic surveys was therefore almost given from the outset as the researcher would be conducting this study in a cultural background situation different from his own. The set-up therefore required a study conducted as close to the local market situation as possible and actual valuation work based on the economic premises of these local households. The household economic surveys thereby became entry points to the whole valuation exercise. Locally collected data provided possibilities to see the full range of variations and valuation approach opportunities behind the statistics, which would be lost in coarser data collected for some other purpose for a larger population or area.

The analytical process for valuating impacts from prosopis should preferably start as an initial environmental examination (IEE) during a recognissance mission to potential research areas and then be followed by an environmental assessment (EA) or an environmental impact assessment (EIA) on this tree at sites that are selected for the actual research study. The EA/EIA assessment work needs to incorporate household, group and professional expert interviews at the framed research sites (as already presented above) in combination with other relevant data collection from the same area. Such household assessments can also simultaneously act as a social impact assessment (SIA) of all population groups with regard to prosopis in the framed research areas. The aim of the assessments should be to identify all the environmental impacts from prosopis on the local households and their respective livelihoods in the area (Dixon and Pagiola 1998; Abeygunawardena et al. 1999).

Even in well-functioning markets there are market failures due to less than optimal provision of goods or services over a given period. One main source of market failure is exemplified by the provision of public goods (Kahn 1998). Such goods have attributes that discourage private markets, as profits and benefits do not allow appropriation by the supplier. These attributes are:

- <u>Non-excludability</u>, meaning that once the goods are produced, non-paying consumers (or free-riders) cannot be prevented from benefiting from using the goods;
- <u>Non-depletablility</u>, meaning that the consumption of the public good by one individual does not diminish its consumption by another individual.

Ecosystem services provided by forests are typical examples of public goods. If an individual or a group owns or controls a forest with rights to exploit it, these people have difficulties in financially realizing a return from the public goods that are provided by it. Therefore there are few financial incentives to conserve natural forests to ensure the provision of such potential public goods (Kahn 1998).

Another source of market failure is derived from the externalities. “An activity is said to generate a beneficial or detrimental externality if that activity causes incidental benefits or damages to others, and no corresponding compensation is provided to or paid by those who generate the externality” (Baumol and Blinder 1982). A broad range of environmental goods and services produced by humans falls into this category, but in nature there also occur damages which are linked at least partly to human activities (such as the land degradation caused by the depletion of vegetation, and by infrastructure development). The latter types of environmental goods and services are in principle outside the definition presented above, but in reality their impacts are for the affected party identical to those of the true externalities. In the Gandato Scheme case, the human-influenced nature disaster-type of externalities occurred, for instance, in the form of sand invasion into the scheme area, which created costs to individual households without compensation, resulting in negative externalities from sand invasion. On the other hand, there also existed human-influenced natural beneficial environmental externalites, for instance, in the form of prosopis that mitigated the sand invasion. Any relevant externalities thus need to be incorporated in the economic analysis either as costs or as benefits to the community or to society at the national level under study. After a monetary value has been assigned on the externalities, these would be entered into the cash flow analysis as any other economic cost or benefit (Dixon and Pagiola 1998; Bishop 1999; Abeygunawardena et al. 1999).

The methodology chapter describes in more detail how the two selected research sites in the New Halfa and Gandato Irrigation Schemes were chosen. Of importance here is that the various ethnic population groups and even individual households within them in the two selected areas indicated diverse views on the environment in their surroundings, and therefore it was vital to be able to compare the empirical results of the study across all households. The study had first aimed at investigating the household cash and subsistence income generation and at clarifying how much and in which ways environmental resources were integrated into household economies. The households investigated in the New Halfa and Gandato Irrigation Schemes were then studied as separate population groups by dividing each population group into cash income quintile categories in order to also determine the differences between comparatively poorer and wealthier households in relation to their environmental resource use (cf. Cavendish 2002). Due to the fact that the New Halfa case included four distinct population groups with distinctly different approaches to their environment, the subsequent valuation exercise for this particular research site focused more on the magnitude of the identified environmental impacts, rather than on calculation of public goods and externalities. A full-scale TEV study would have demanded more time and research efforts and several alternative scenarios.

The Gandato Irrigation Scheme area included households that belonged to different ethnic backgrounds with either farming or pastoral lifestyles, but during the last five or so decades of increasing desertification these diverse people had slowly been merged into a fairly homogenous population group that was studied as one entity. In the case of this framed research area there was also more need for in-depth environmental economic impact analysis, since the area had experienced a serious sand invasion and had a harsher climate on which the initial environmental examination (IEE) indicated substantial mitigating externality services provided by prosopis. Without an externality analysis approach the impact of prosopis on mitigating the sand invasion would have escaped economic incorporation.

Sand invasion caused a substantial economic burden and resettlement of the population in villages which were not protected by shelterbelts with prosopis. Cernea (1999) has differentiated eight main risk categories affecting households which have to involuntarily resettle at a new location in a developing country. These risks are: (a) landlessness, (b) joblessness, (c) homelessness, (d) marginalization, (e) food insecurity, (f) increased morbidity and mortality, (g) loss of access to common property, and (h) social disarticulation. The sand invasion in the Gandato Scheme did not constitute an instant acute natural disaster or catastrophe. This reduced the above-mentioned risks to some extent, as the households could plan and prepare their emigration for a longer time and even have all their movable belongings transferred with them to the new location. Some risks are unavoidable, though, both for the households that stay in the villages invaded by sand and for those that leave the village for good.

By definitions of environmental (or ecological) economics, non-market values are anthropocentric in nature. Economic values are the worth of goods or services to an individual or a group of like-minded persons in a given context. Apart from the economic values there also exist philosophically determined values dealing with ethics. Values are often complex, and the reference to a given context as described above is fundamental, as there normally is not only a single value for a good or service, but instead a range of values associated with given resources or services. Values are not static but may change dynamically over time as people and conditions change. Therefore, in this study, valuations were directly associated only with the people belonging to the communities of the framed research area in the Gandato Scheme during the fiscal year 2002 - 2003. A primary aim of this kind of externality valuation exercise was to provide scientific support for decision-making in and for the area analyzed, but an attempt was also made to provide potential support for decision-makers elsewhere as well (cf. Kengen 1997; Johansson-Stenman 1998; Bishop 1999).

### 3.2. Earlier literature on Total Economic Valuations

For conducting a comprehensive economic valuation of environmental impacts caused by a specific factor in a given area, there has during the last years been an increasing interest on the use of Total Economic Value (TEV) analysis. The TEV approach is not merely a summation of estimated values derived from environmental services using various methods and techniques available. It also assumes that all overlapping of monetized values is filtered out (Kengen 1997; Abeygunawardena et al. 1999). Additionally, competing values often exclude each other from a scenario. Consequently, one may have to choose one or more scenarios to calculate alternative TEV values for each situation.

The concept of TEV was introduced in the early 1980s by economists in the wake of the rising environmental awareness. International financing institutions such as the World Bank and the Asian Development Bank became involved a few years later, when a need arose to determine how environmental concerns were taken up in the financing institutions' development projects. Relevant guidelines for conducting TEVs were therefore prepared. Three model case studies prepared by the AsDB were, for instance, conducted for the "Forest Sector Project" in Bangladesh, the "Central Sulawesi integrated area development and conservation project" in Indonesia, and the "Upper watershed management project" in Sri Lanka (Abeygunawardena et al. 1999). Researchers also started to use the TEV concept more frequently. Costanza et al. (1997) published in Nature a much debated article on economic valuation of ecosystem services for the whole Earth, which was based on data and information from a broad spectrum of studies by researchers around the world. In the 21$^{st}$ century it has become even more common to conduct TEV exercises in relation to natural resource valuation and management. TEVs have, for instance, been completed for the Leuser National Park in Sumatra (van Beukering et al. 2003), the whole forest sector in Uganda (Bush et al. 2004) and for valuation of forest resources in the whole of the Mediterranean region including 18 countries within the MEDFOREX project framework (cf. Croitoru 2007). Recently a wetland valuation manual with case studies with an important role for TEVs was published by the Ramsar Convention Secretariat (de Groot et al. 2006).

Recent developments of the TEV approach have also tried to measure a willingness-to-pay (WTP) holistically by using a stated preference approach whereby the result is one value instead of a disaggregation of several values derived through component parts. This kind of a complex interview approach requires that the respondents state their WTP based on consideration of all their possible motivations. Such a TEV approach may not be useful in rural developing country context, since the results depends on the analyst's ability to construct a meaningful structured conversation between himself/herself and respondent (cf. Boardman et al. 2006).

Apart from the above-mentioned and similar TEVs, there are also various other economic valuation exercises that partly follow the TEV concept. A study on the cost-to-benefits ratio of wildland fire prevention in southern France was, for instance, conducted on dry Mediterranean forest lands near Marseilles (Alexandrian et al. 2005), and an evaluation of the European policy on forest subsidies in terms of social costs and benefits of the Spanish afforestation programme was conducted by Riera and Mavsar (2005). The TEV analysis approach has also been used in valuation of alien invasive species, for instance, in a study on black wattle in South Africa (de Wit et al. 2001).

### 3.3. Total Economic Valuation and its prerequisite stages

Valuation of forest environmental resources and their respective impacts is important in most forest environmental decision-making processes, but it gives no single best solution for the handling of these difficult problems. A valuation should be understood as a neutral analytical tool that brings in holistic information to support a decision-making process, without necessarily providing straightforward conclusions. Often its main contribution lies in showing that the sustainable use of forests has a positive economic value, although this may not earlier have been evident. Further, this value is often even higher than that from alternative options in which the resource is lacking or found to be less abundant. A valuation exercise can be expected to influence the perceptions of sustainable development in a given place; otherwise the whole exercise would be a wasted effort. Further, it should indicate at least the order of magnitude of environmental impacts; this could then support the formulation of investment decisions needed for rectifying the situation and the choosing between alternative investment strategies. The most appropriate valuation techniques are tailor-made and separately selected for each valuation situation, with no rigidly fixed mind-set determining the approach, since even in similar-looking cases the opportunities available for data collection may be diverging (Kengen 1997).

An environmental market and non-market valuation should be combined with the use of cost-benefit analysis (CBA), which is the normal approach to the valuation of a full range of environmental impacts of a development project or investment alternatives. A CBA in a natural resource project needs to be calculated for the internal rate of return (IRR) on investments for benefits or for the mitigation of negative impacts on the environment. The CBA testing of a project or an investment is acceptable when the value of environmental benefits at an acceptable IRR equals or is greater than the value of environmental costs at Net Present Value (NPV). The acceptable level of IRR on investments is usually set by the investor (or the researcher) as a percentage equal or higher than 10%. The end result of such calculation will lead to one of three different scenarios concerning the environmental impacts under study. The most wanted IRR test result is the win-win scenario where the project activity or investment results in an increase in human well-being and stabilizing/rehabilitation of the ecosystem services. Another scenario is a kind of compromise, a trade-off scenario where the project activity or investment results in an increase in some benefits but reduces some other benefits to an extent. The third and least wanted scenario is the worse-off scenario where the project activity or investment damages or destroys the ecosystem services while it provides less benefits than before (Abeygunawardena et al. 1999).

The theoretical basis for cost-benefit analysis is provided by the Kaldor-Hicks criterion (which is also the concept of Pareto improvement). The acceptability of Pareto improvement does not require that the winners of a particular activity (project or investment) would actually offer compensation to losers. Rather it requires that winners can potentially compensate the losers and that compensation is not necessarily borne by the winners (Munasinghe 1993; Bishop 1999; Abeygunawardena et al. 1999).

The use of the CBA approach in connection with environmental economic analyses encounters many potential problems which need to be solved or circumvented. First these need to be identified and then tackled with the best possible solutions tailor-made for the particular research question under study. Hanley and Spash (1998) and Abeygunawardena et al. (1999) provide guidelines for conducting a CBA, which in the present study have been modified so as to cover for an analysis of the impacts of an alien invasive tree species.

The nine stages used were as follows:

1. Framing of an area for the study with clear research objectives and clear demarcation in the field of both the land area and the human and livestock populations covered;
2. Identification of factual impacts caused by prosopis in the framed area only;
3. Screening of economically relevant impacts of prosopis in that particular area;
4. Physical quantification of relevant impacts and a descriptive treatment of impacts which cannot be properly quantified;
5. Monetary valuation of quantified impacts and description of unquantifiable positive impacts;
6. Discounting cost and benefit flows;
7. Applying the Net Present Value Test or Benefit/Cost Ratio Test;
8. Sensitivity analysis of the results; and
9. Checking the validity of the results.

Due to challenges (such as drought, poverty, desertification, floods, pests, inflation, policy failures etc.) which are particularly pertinent in rural areas of developing countries, a decision was made to conduct the current CBA analysis for a time-slice of a one-year period only. Consequently, the main emphasis for the analysis was on steps 1 – 5 and 7 above. The one-year time-slice approach is feasible, since the impacts of prosopis in the framed research areas have already been seen in full scale for the last ten years or so. Therefore the years just preceding or directly following the one-year time-slice now studied would have shown overall impacts quite similar to those from the selected financial year while reducing the disturbing impacts of the above-listed challenges.

Despite obvious challenges, a non-market valuation is sometimes even more important than the market valuation in developing countries in which both the national economy and the rural micro-economies are strongly natural resource-based, with many non-market priced goods and services involved. The existence of many non-market values greatly hampers the decision-making in different situations. Frequently some relevant impacts are left out (by mistake or on purpose), leading to inaccurate CBAs, which in turn means that wrong projects or investments may be undertaken. Therefore, care has to be taken to ensure that all relevant impacts are included. A CBA is normally most suitable for small-scale decisions, as it is generally based on the assumption that a project or an investment alternative will not alter the prices or the structure of a wider economy (Abeygunawardena et al. 1999; Bishop 1999).

The conducting of a TEV analysis should not be the first choice among the methods available, as it is so cumbersome. Only if relevant partial valuation methods prove inadequate in providing a convincing basis for judging the relative advantages of alternatives should a TEV analysis be implemented. It is normally difficult to calculate the whole range of values needed in a TEV analysis, and this may even be meaningless from the outcome point of view. A more realistic approach is to focus on the dominant impacts and to describe in positive or normative terms the remaining impacts under study, without monetizing them. In fact, over-ambitious attempts to present everything in monetary terms may be counter-productive, as some estimates generated are then not likely to be credible and may lead to lack of confidence in the valuation results among decision-makers (Kengen 1997; Abeygunawardena et al. 1999).

The contents of a TEV analysis vary slightly from case to case and from analyzer to analyzer, partly because it is a demanding task which requires large amounts of data and is both expensive and time consuming. The valuation work aims at identifying, quantifying and monetizing or describing: (a) the direct use values, (b) the indirect use values, and (c) the non-use values. *Direct use values* refer to the purposeful use of bioresources to gain an economic benefit or utility. Bioresource goods can be consumed by households which hunt, collect or grow them, use them as raw materials, or trade in them. Other use values, related to recreational activities, are for instance, sport fishing and hunting, ecotourism, and bird-watching. *Indirect use values* are associated with functions of the ecosystem that maintain the stability and productivity of the environment. On a wider scale, values also include the environmental services of watersheds in the hydrological cycle, and the contributions of forests and other types of vegetation to the atmospheric balance and climate regulation. Bioresources can also be valuated for the aesthetic, cultural, spiritual, or recreational benefits they provide. There are also so-called *option values* for such utilization, which may not be alternatives in active use but ones that can be taken into use at a later occasion (Dixon and Pagiola 1998; Abeygunawardena et al. 1999).

The *non-use values* include *existence values*, which represent the value of the satisfaction an individual derives from the knowledge that a given element of biodiversity exists, irrespective of whether that individual expects to use or benefit from it directly. There are also *bequest* values, where goods or services are saved for future generations to experience. Additionally, there are *intrinsic values*, which relate to ethical, moral, or cultural perceptions, for instance, including expectations that giant pandas should still exist or that a given type of ecosystem can still be found intact on the Earth. Figure 1 presents the various categories of values that potentially could be included in a TEV analysis and the main valuation approaches considered for the present study (Dixon and Pagiola 1998; Abeygunawardena et al. 1999; Grimble and Laidlaw 2002; CBD 2003).

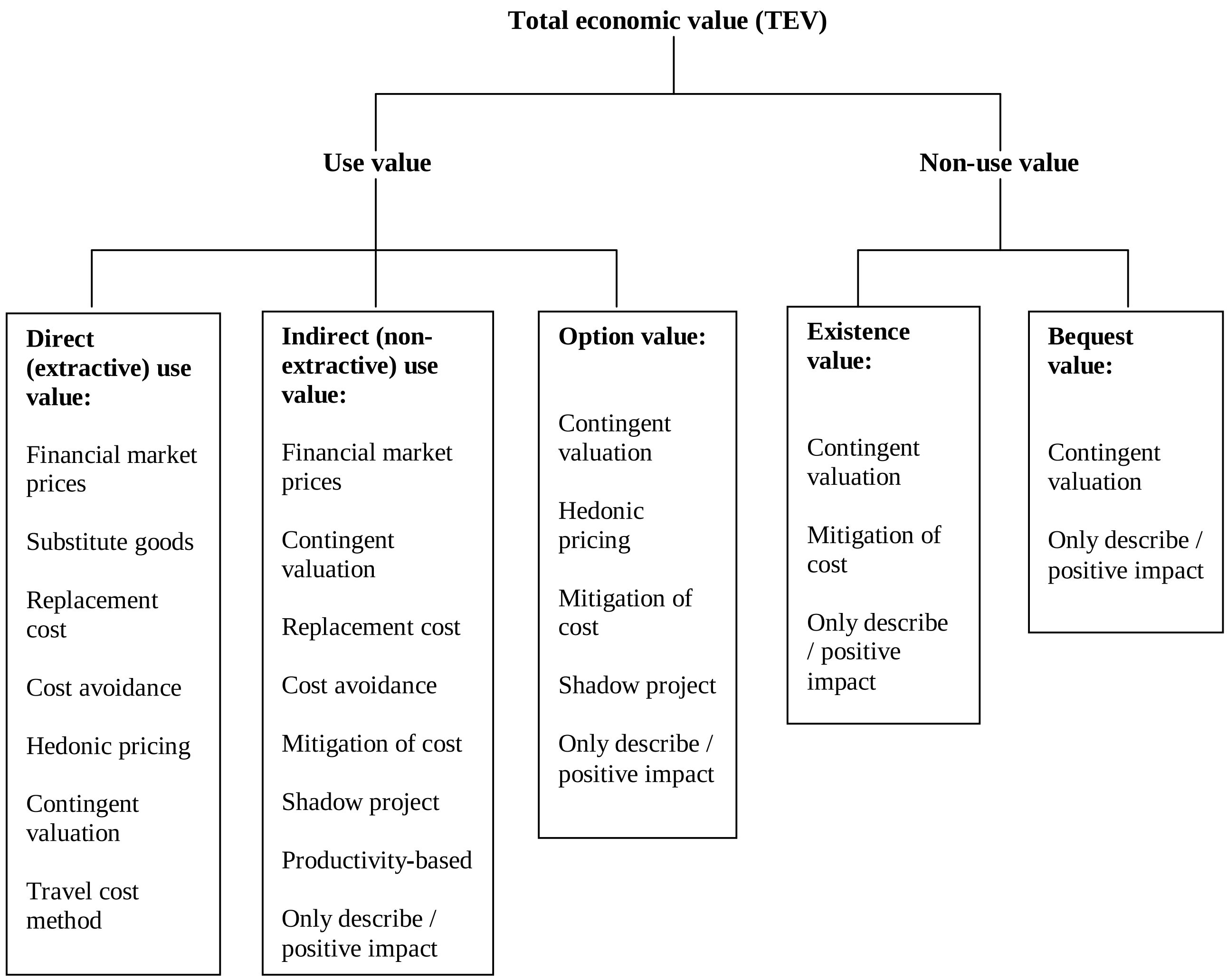


Figure 1. Components of Total Economic Value (TEV) analysis and potential valuation techniques considered for the present study (modified from Dixon and Pagiola 1998).

In the context of rural Sudan, option values as well as existence and bequest values are often difficult to quantify and monetize; perhaps they are also at least partly non-existing (in the minds of the local people), due to the differences in environmental awareness between societies in Africa and in the developed countries. The resulting overall TEV value in the present study was mainly focused on use values and, where possible, also on indirect use and some intrinsic values. In this way the TEV outcome could be assumed to be sufficiently concrete and credible – an advantage particularly for the benefit of decision-makers, who would need to justify their decisions for the public at large. It is comparatively easy to conceive that if the perceived accumulating benefits from prosopis are greater than the respective costs, then the TEV of prosopis would be more beneficial than detrimental to the site investigated. This can be stated in a more popularized form as given in the title of the present study: to determine whether prosopis is a curse or a blessing at some representative site under investigation.

It is a normal environmental (ecologic) economic valuation custom to investigate whether a situation with a specific impact (activity or investment alternative) is better than a situation without this environmental impact (Dixon and Pagiola 1998; Abeygunawardena et al. 1999). The CBA approach is normally used to determine whether afforestation would economically be justified in comparison to the best alternative use. For instance, Pierce (1994) used a mathematical statement for the CBA analysis of his landuse study, which in slightly modified form could also be used for investigating whether a scenario with prosopis (A), was better than another without prosopis (B), for a given site under investigation. The modified version of the mathematical statement by Pierce could be written as:

$$B_a – C_a > B_b - C_b \qquad (1)$$

Where $B_a$ = benefits of current situation with prosopis;
$C_a$ = costs of current situation with prosopis;
$B_b$ = benefits without prosopis;
$C_b$ = costs without prosopis.

The above statement for the two scenarios, A and B, can be operationalized as follows:

$$\sum_{i=1}^{k}(B_{ai} - C_{ai}) > \sum_{i=1}^{k}(B_{bi} - C_{bi}) \qquad (2)$$

Where $i$ = includes all studied benefit or cost categories.

Pierce's statement above has been criticized by Perman et al. (1996) for being incorrectly constructed to justify the economic calculation for his afforestation case. According to the criticism it is sufficient that $B_a > C_a$ and there is thus no need to compare it with another best alternative scenario. However, for the current study on prosopis where scenario A already exists, the original equation used by Pierce (1994) fits perfectly the research aims.

The actual data collected should be of good quality and include both biophysical and socio-economic relevant elements. However, most TEV analysts, particularly when working in developing countries, will have, to some extent, to rely on rough estimates. Such an approach needs therefore to have solid scientific information in the background that can reasonably well support the assumptions used (Kengen 1997). Care has also to be maintained throughout the process for not to double-count impacts within a TEV scenario or impacts from another TEV scenario as part of the scenario under study. Unfortunately, many TEV studies in the past have relied heavily on fairly crude assumptions or even on secondary data sources with not much connection to the actual valuation site and not described well the primary source nor the actual assumptions behind the data; therefore, the overall validity of the results has been difficult to ascertain (Bishop 1999). The present study attempted as much as possible to use specific locally accumulated data, as well as secondary data from other researchers and natural resource managers active in the area or in similar conditions in Sudan or elsewhere.

Figure 1 also presents the main valuation techniques and the respective valuation categories under which the selected valuation approaches belong in the TEV analysis. These valuation techniques as applied in developing country contexts have, for instance, been described by Kengen (1997) and Bishop (1999). The valuation techniques can be divided into (a) revealed preference, (b) stated preference, and (c) cost-based approaches. The revealed preference approaches include direct market price approaches, surrogate market price (Hedonic Pricing, Travel Cost and Substitute of Goods methods) and production function approaches. The stated preference approach group comprises, for instance, the Contingent Valuation Method (CVM), Con-joint Analysis, Contingent Ranking, Choice Experiments, Choice Modelling and Participatory CVM. Cost-based valuation contains such approaches as Replacement Cost, Avoidance of Cost, Mitigation of Cost, Opportunity Cost of Labour and Shadow Project. The production function approach, production-based approach and dose response approach are largely identical techniques, with different names for different situations.

Almost every step in any of the above assessments involves values or value judgments, as the very selection of a particular valuation approach is a value judgment. Excluding values and value judgment is not even advisable, as they represent the basis for understanding the political nature of regulations and decisions that relate to environmental health, land degradation or biodiversity conservation (Cothern 1996; Johansson-Stenman 1998). Without a comprehensive picture it is hard to know the right direction of actions included, and the risk of making wrong decisions is imminent.

ADB (1996) and Abeygunawardena et al. (1999) have provided some guidelines on how environmental impact screening could preferably be conducted in projects. However, the task of impact screening is not a straightforward process in reality. It is more an evolving process with movement both forward and backward until various impacts have been screened in terms of quantities and subsequent monetization of the accrued beneficial and cost values.

The screening process should preferably incorporate the following:

- Start with the most obvious and most easily valuated environmental impacts that normally can be directly measured in money terms according to (financial) market prices;
- Consider both the benefits and the costs of an action or investment (in this case all impacts of prosopis);
- Conduct a comparison between the “with the project” and the “without the project” situations, i.e. the scenarios A and B described above in this particular study;
- All assumptions (biophysical, social and economic) of the economic valuation need to be clearly stated;
- Prior to the integration of monetized values, the values should be converted into economic values using appropriate conversion and other factors as justified by the situation.

The quality of the results in terms of their credibility should be evaluated (cf. Hanley and Spash 1998). This is best done by considering the three concepts of (a) the repeatability of results, (b) the validity of results, and (c) the esteem that the method holds within the academic community. Among environmental economists it is commonly considered that stated preference techniques are best able to distinguish non-use values. The credibility of the results can thereby be seen as either related to how many of the non-use externalities have been left out from the monetized values derived through revealed preference and cost-based approaches, or, in the case of stated preference approaches, to the question to what extent monetized values can be concretely separated into various interconnected values for one environmental service. It is often difficult to ascertain the credibility of values derived using stated preference approaches, particularly for complex environmental and ecological valuation excercises. Repeatability is relatively easily achieved with the revealed preference and cost-based approaches. The validity of the results of these two valuation approach categories can to a large extent be determined for any concrete parts of the externality values. The question remains, however, to what extent externality values have has been included and often there is no clear answer. The validity of the results does therefore in these cases not fully cover all the externalities. The esteem before the academic community is then a more subjective testing criterion, particularly in developing country contexts.

The performing of the TEV analysis of the present study had the following strategic prioritization and focus (cf. Kengen 1997; Farley et al. 2005):

(a) Several impacts that were difficult to measure were from the start known to be undisputably positive in nature at the particular sites studied and these were thus left at the normative and positive description level only. These included, for instance, the protection of biodiversity, the historical sites as well as the rehabilitation of soils;
(b) The own data collection needed to be complemented with results obtained by other researchers and pragmatic managers, so as to cover all the multi-disciplinary issues of the study;
(c) Due to the complexity of the analyses, too much effort could not be devoted to each step of data collection. It is also frequently the simplest techniques that are the most useful in capturing realistically the various values of environmental goods and services. A thorough understanding of the relevant ecological, socio-economic, economic and other issues is required, though, for success in this approach;
(d) The data collected, the analyses and the results needed to be checked and compared through triangulation and the income measurements needed to be tested where possible;
(e) In cases where shadow projects or other methods unable to capture the relevant value from an environmental service directly were used, there was a need to derive a minimum estimate of the true costs of this service. The reasoning was that it is better to arrive at a modest than at an exaggerated estimate;
(f) The problems under analysis had to be well-structured and goal-oriented, to the extent that there was a logical flow in the valuation process. The outcome was to provide clear and realistic answers to the initial research objectives formulated for the study;
(g) The main aim of the study was more to estimate the magnitudes of impacts rather than the precise explicit TEV values, which could not even be credibly obtained for all externalities.

During the years there has been some criticism on the use of the TEV approach for natural resources. Part of it has been concerned with the question whether one can even valuate ecosystem services with economic tools and then rank the decisions based on these values. Costanza (2006) argues that economic valuation of ecosystem services is no over-ruling solution for determining the importance and management of such services. Rather, it is a way of gathering helpful information for decision-making in relation to the sustainable management of complex natural and other resources. He also argues that nature contributes significantly to the human well-being and is therefore a major contributor to the real economy. Thereby the choice is directly related to how the Earth’s natural resources as well as our human-made capital could be managed, more effectively and more sustainably.

Another, more pragmatic part of the criticism has concerned the results achieved to be used for decision-making. The earlier mentioned article by Costanza et al. (1997) has been, for instance, fairly heavily criticized for its construction of the TEV analysis and for its findings (cf. Bockstael et al. 2000). The article aggregates and scales up a variety of estimates of economic values taken from other studies of ecosystem services and functions to provide values for the whole Earth. Bockstael et al. (2000) argue that it is unjustified to extrapolate such value estimates outside their valuation contexts. Such an exercise does not have valid foundations. The above example is in the mega-scale, but other researchers have also conducted TEVs with data from smaller areas or districts that have been extrapolated to cover whole countries. The work has often been conducted as a desk study from the start, using available data and pieces of fairly generalized information, which have been compiled into a set of benefits and social costs to make up the whole range needed for an economic valuation analysis. In such cases there is normally no real framed area for which quantified impacts are first assessed and then monetized.

A third problem raised has been whether the TEV analysis results in overlapping intangible externality benefits that are hard to separate due to their abstract nature derived from the stated preference valuation techniques (cf. Croitoru 2007). It is therefore important to use more modestly monetized values than overambitious values.

A fourth problem with TEV studies concerns, for instance, as pointed out by Spash and Vatn (2006), the fact that the researchers have often not collected all the data they utilize through their own research activities or from somebody else's research findings from the actual site of study. Instead, they have transferred information from other sites within the country, from the region or even from another continent. Often this borrowing and transferring of values is conducted from other economic studies without much consideration of the original context or the theoretical basis of those values. This problem primarily concerns values derived through stated preference techniques, which are exceedingly difficult to revise for another site. Concrete direct use values are easier and more likely to be adjusted or recalculated properly with additional information from the site under study.

### 3.4. Standardizing of income measures for household economics

Elements of resilience in response to various constraints, such as drought and heat, lack of political power, insufficient management and administration, undeveloped logistics and infrastructure, insufficient economic safety nets, and a low level of education etc., make a clear adoption of the maximization theory difficult in the context of poverty-stricken developing countries. However, it is useful to enable a standardized comparative analysis of forest-related household income and its links to poverty reduction. A standardization of household income variables also enables a linking back from empirical results into theory.

In the case of prosopis, it is necessary to revise the monetized value of free-grazing forage obtained from the commercial replacement cost value of fodder derived from household surveys as presented in chapters 4.3.2. and 5.2. Therefore another value for free-grazing forage was included. The new value was calculated based on the total monetized subsistence value and net annual value of milk, meat and animal sales for each household, respectively. In this way the monetized forage value was financially internalized into the household economy. This joint value was then divided into per cent shares for each type of fodder used to feed each respective household's livestock. The percentage shares of the value for prosopis and other types of free-grazing forage were then included into the forest environmental subsistence income.

The following standardized definitions are presented by Vedeld et al. (2004) and repeated here to clarify the household economy results. The first variable used in measuring of income is

**AI** = absolute total income

which is the same as each household's total cash and subsistence income from all income sources. Another variable is

**ACI** = absolute cash income

which is the cash income from all available sources. The pair to ACI is then

**ASI** = absolute subsistence (or in-kind) income

where **AI = ACI + ASI**.

Each of the variables above has its respective counterpart for the forest environmental income. The first is

**AFI** = absolute forest environmental income

which is the total forest environmental income from all cash and subsistence income sources for a household. This can then be divided into

**ACFI** = absolute cash forest environmental income;  and

**ASFI** = absolute subsistence (or in-kind) forest environmental income.

Further, a new variable for the absolute non-environmental income is constructed; that is, the absolute income from all sources other than the forest environment, which would be then

**ANI** = **AI – AFI**

It is, furthermore, equally important to measure the relative forest environmental income against that from all sources. First there is then

**RFI** = relative forest environmental income = **AFI / AI**

which measures the relative share of the absolute forest environmental income in relation to the absolute income. The equivalent for cash income is

**RCFI** = relative cash forest environmental income = **ACFI / ACI**

which measures the share of the absolute forest cash income in relation to the overall absolute cash income of a household from all sources. The pair

**RSFI** = relative subsistence forest environmental income = **ASFI / ASI**

measures the share of the absolute forest subsistence income in relation to the overall absolute subsistence income of a household from all sources. The relative income measures can also be calculated for prosopis and other environmental sources separately.

Further it is useful to study income inequalities and distribution problems. The distribution of the total income between households in a community (or province or country) is called the personal income distribution. There is no actual theory according to which one could explain the distribution of income, but there are some useful ways to measure and describe it. One such description is the Lorenz curve, where the X axis shows the households in a community (sample) in terms of cumulative percentages from the lowest to the highest income. The Y axis shows the percentage of the total income. In case the distribution of income is the same among all households, there would be perfect equality among households. This would be shown as a 45-degree line from the origo to the point where the highest household income meets 100% of the households (i.e. point 100%,100%). The Gini coefficient is the discrepancy between the actual income distribution and the line of perfect equality. Thus, for perfect equality, the Gini coefficient is zero and for perfect inequality the Gini coefficient is 1 and takes then up the whole area under the 45-degree line (Daly and Farley 2004). According to Vedeld et al. (2004), the Gini coefficient can be calculated as

$$G_{AI} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} |AI_i - AI_j|}{2n^2 \mu} \qquad (3)$$

where n is the sample size, *i* the sample household number, *j* another household sample number where $i \neq j$, and μ is the mean value. If the AI values are first placed in ascending order then some of the above comparisons can be avoided and the computation becomes simpler (Buchan 2006; Miyamura 1997):

$$G_{AI} = \frac{2}{n^2 \mu} \sum_{i=1}^{n} (AI_i - \mu) \qquad (4)$$

In many studies an optional Gini coefficient has been calculated for the total non-environmental income (ANI) and then this Gini coefficient has been compared with another for the absolute total income (AI). However, due to the fact that ANI and AFI are closely intertwined in both livestock rearing and crop cultivation, this is not a realistic option. Without the free forage or prosopis weeding options, there would in many cases be no ANI livestock or crop cultivation income either. It may instead be better to just present ANI in the same Lorenz curve with AI and in this way show the share of ANI in relation to AI for each specific household.

In addition, comparisons between the wealthier and the poorer households in terms of forest environmental income and dependence are of interest in general, regardless of the specific nature of the relationship. An Absolute Kuznets Ratio is the ratio between the average incomes of the wealthiest x percent with the poorest x percent. The Absolute Kuznets Ratio (AKR) is then

$$AKR_i = \frac{\text{mean AI (wealthiest 20\%)}}{\text{mean AI (poorest 20\%)}} \qquad (5)$$

where the index *i* denotes the population group studied.

# 4. MATERIAL AND METHODS

## 4.1. Screening and data collection process

### 4.1.1. Selection of suitable research sites

As explained above in sub-chapter 3.1., the data collection started with an initial assessment of the impacts of prosopis at the potential research sites. Therefore the actual research work started with the preparation of a list of potential benefits and costs from prosopis, compiled from the available literature and from reports on the opinions of Sudanese authorities and local people in the potential research areas in Sudan. This list was then used in January 2003 during Initial Environmental Examination (IEE) or the reconnaissance trip to Sudan, which was conducted to select the research sites suitable for the work as well as to conduct a first impact screening, so as to better understand what kind of benefits and costs would have to be valuated. The impact list contained around 130 different impacts from prosopis, and then in the field the actual benefits and costs encountered were ticked off from the list at each site. Locations visited were the Khartoum city (for urban forestry); the New Halfa Irrigation Scheme, the Kassala town and the seasonal Gush river in Kassala State; the Port Sudan outskirts and Tokar Gush in Red Sea State; the El Qitana area; the Kosti and Tendelti surroundings in White Nile State; the Al Bashiri village and the Bara town oases of North Kordofan State, as well as the surroundings of Shendi in River Nile State. A few months later while starting up the actual data collection, the Ed Debba (Ergy) and Dongola surroundings in Northern State were also visited. Each locality showed its specific features.

The study had to be focused on one or two framed sites, so as to be manageable and clear for one researcher to conduct. Most sites appeared to have either a narrow spectrum of benefits and social costs, which made them less attractive from a research point of view, or then there were logistical problems related to remote locations. Due to these reasons, the optional sites in Kosti, Tendelti, Kassala Gush, Port Sudan, Tokar Gush, Al Bashiri, and Bara were left out. The El Qitana area was found to be an option similar to the Shendi area, with a little more pronounced aridity in the latter, which made the selection of the latter a slightly better option for the study, added with the importance of specifically incorporating River Nile State or Northern State into the analysis.

The Ed Debba and Dongola sites in Northern State were assessed during the IEE process as the most obvious cases for predominantly positive impacts of prosopis. The populations of these two locations were aware of positive effects of prosopis, and even the state administration was reluctant to start any eradication of prosopis in accordance with the Presidential Decree. Since the outcome of research at these sites could be anticipated as becoming clearly positive for prosopis and since it also would have become logistically difficult to carry out data collection there, these two sites were eventually omitted.

The final selection of research sites therefore fell on the New Halfa Irrigation Scheme in Kassala State and the Shendi area in River Nile State. The New Halfa Irrigation Scheme was in 2003 the best-known negative case for prosopis in Sudan; the fact that the scheme area is predominantly located on clay soil also supported its selection. It would thereby act as a case contrasting with the other site selected, which was an area in the Gandato Irrigation Scheme adjacent to Shendi, about 130 km north of Khartoum along the Nile. In this scheme the perception of the population was more ambivalent towards prosopis, while it also represented a clear case for prosopis on sandy soil. These two selected cases thus complemented each other, making the research more useful for possible generalizations also in respect to other sites in Sudan and elsewhere in tropical drylands.

### 4.1.2. Selection of overall approach for the valuation excercise

During the initial planning of the research for this study, there were a few useful references available which each provided parts of the overall framework for the work. The best sources for the planning of the overall strategy for the present work included the following: ADB (1996), WB (1996a, 1996b and 1997), Hanley and Spash (1998), Dixon and Pagiola (1998) and Abeygunawardena et al. (1999). These references stressed, among other issues, the need to frame the research areas and holistically valuate the impacts at the selected framed research areas only. The study planning was also shaped using information from the following sources: Munasinghe (1993), ADB (1999), Alcamo (2001) and Nemarundwe et al. (2003).

From the start there appeared a need to understand how rural households make their day-to-day decisions regarding prosopis and other factors that impact on their livelihoods. For a household survey, Cavendish (2002) and Campbell and Luckert (2002) provided tools for obtaining baseline data. During the process of work some other important sources were identified such as Pierce (1994), Kengen (1997), Bishop (1999), IUCN/WB (2004), Vedeld et al. (2004), Daly and Farley (2004), Farley et al. (2005) and Giovannini and Linster (2005). The importance of these latter reference works has been in confirming the strategic choices, valuation approaches and solutions that had already been taken during the analysis process, as well as in supporting the standardization of the results.

The data collection was based on and consisted of an initial environmental examination (IEE) followed by household economic surveys that were a combination of an environmental impact assessment (EIA) and social impact assessment (SIA), thus providing a good basis for a Total Economic Valuation (TEV) study with both monetized impacts and impacts of prosopis that could be defined as positive but were left non-monetized. This task was, due to its complexity, demanding and time-consuming; it was carried out only for one of the two framed areas. The actual way of execution of this research evolved from an increasing understanding of the situation and the actual data collected or retrieved from other researchers.

An important piece of methodology adopted from ADB (1996) and Abeygunawardena (1999) and substantially modified was the environmental impact screening process, which emphasizes the selection of the most important benefits and costs for valuation in the TEV study. The overall structure of the work conducted for this study is presented in Figure 2. The process of collecting data for the TEV was to analyze and synthesize the data from household surveys and other basic data sources, which could then be utilized in subsequent analyses as data compiled from the area. In this way comprehensive cases were slowly built up from which an overall synthesis could be derived. As seen from Figure 2, there were many separate stages in the impact screening as this was not a straight-forward activity due to lack of quantified data at the outset. These separate stages of impact screening needed support by new data collection in the form of individual household surveys, statistics, satellite images, soil analyses and previous research results of other researchers until a final quantification and monetization in the environmental screening process could be carried out.

At the start-up, various valuation techniques were considered for adoption. These included contingent valuation, con-joint analysis, the travel cost method, hedonic pricing, and some other valuation techniques commonly utilized in industrialized countries. In the end, however, all of these approaches were discarded for various reasons. For instance, the above methods require that the population in the framed research area has a fairly high degree of environmental awareness and is used to handle complex monetary decision-making situations. Many of these methods appear to have been used successfully in Africa so far mainly in connection with eco-tourism and urban populations (cf. Boxall and Beckley 2002).

Con-joint analysis was first seriously considered as a suitable option in which the household respondents could rank attributes shown either as text or as picture/photo cards, thus restricting their choices. However, the text card option was discarded first, as many of the interviewees were expected to be illiterate or poorly educated and speaking different languages without control mechanisms for translation and interview stages. Picture/photo cards were also a risk, as it could not be foreseen how people of various age and ethnic backgrounds would actually interpret them (cf. Emerton 1996a, b; Tano et al. 2003). The risk was therefore high that the interviewees would have interpreted issues completely differently from what was intended; and therefore an objective outcome was not likely to be achieved without some substantial trial and error activities.

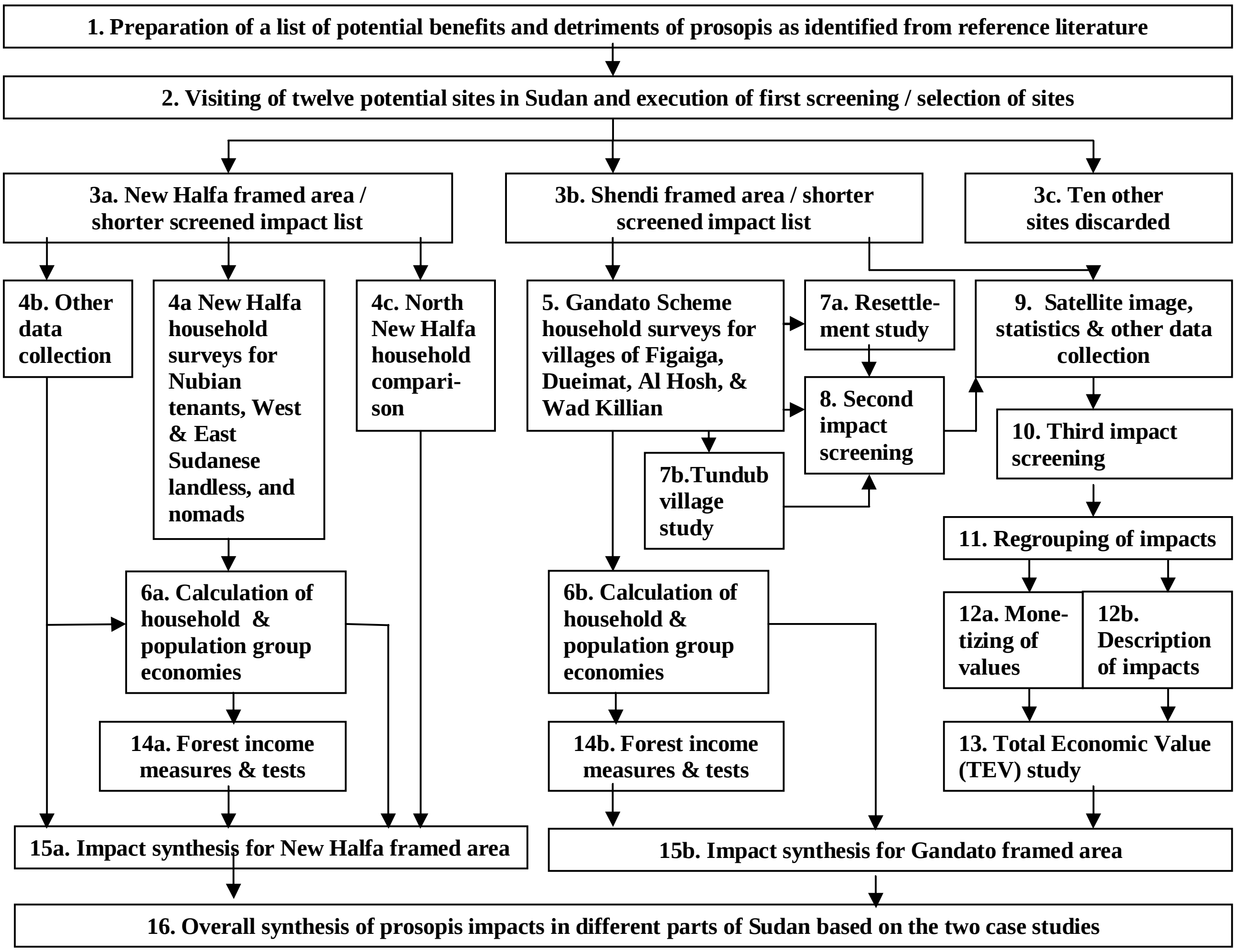


Figure 2. Outline of the research and stages of its execution (shown by numbers).

What most of all constrained the selection of valuation techniques from the start was the fact that the actual benefits and social costs for the analysis were not properly known at the outset. Another issue was that a large number of impacts were foreseen to be analyzed to enable the forming of a comprehensive picture of the prosopis impacts. To focus the valuation on just a few benefits and costs was not a feasible option for studying the range of impacts of prosopis. A decision was therefore made to focus on simple and realistic methods and to keep the actual valuations close to the markets where they appeared.

The principal aim with questionnaires was to get an understanding of the welfare and livelihood situation of each population stratum in the framed areas and to see how prosopis enters into the economy of each household in the selected communities. The questionnaires were based on several simple questions which could be easily translated from English to Arabic by Sudanese foresters and other professionals acting as translators. In this way, most translation mistakes and other misunderstandings could be avoided. Furthermore, the local respondents with vastly varying ethnic backgrounds and education levels could respond satisfactorily to the questions without fear of too difficult questions. This contributed to a friendly atmosphere between the researcher and his team on the one hand and the villagers or the local authorities on the other.

The survey interview results from individual household questionnaires were fed into the Excel programme, and individual household incomes and costs were subsequently calculated for the financial year 2002 – 2003. The financial year as now applied started with the beginning of the cropping season in June 2002 and ended one year later in June 2003, following the cultivation schedule of irrigation schemes. The questionnaire was prepared for construction of the full-fledged absolute total incomes of households (Cavendish 2002; Campbell et al. 2002; Vedeld et al. 2004), but adjusted and expanded to some extent by the inclusion of additional non-market subsistence income and the main known household costs.

### 4.2. Study site descriptions

**The New Halfa Irrigation Scheme.** The Scheme, located in the western part of Kassala State, about 400 km east of Khartoum, was established between 1962 and 1969 partly with Egyptian grant funds. The reason was primarily to resettle the Nubian (Halfawyeen) people displaced when the Wadi Halfa town surroundings became inundated by Lake Nasser as a result of the Assuan dam construction in the 1960s (WB 1992; Drupsteen et al. 1989a; Drupsteen et al. 1989b). The scheme stretches 115 kilometres in north north-west direction and has a width of 30 to 35 kilometres on the western side of the Atbara river (Agrar und Hydrotechnik 1978). Inside the scheme there is a sugar factory with 10,000 ha of sugar cane plantations which do not belong to the New Halfa Irrigation Scheme Corporation.

The scheme has been designed to use annually, 1,620 million $m^3$ of water from the Atbara river that was to be stored in the Khasm-al-Girba dam that originally had a maximum 1,300 million $m^3$ storage capacity in 1964 (Halfa Aljedeeda Agriculture Corporation 2003). This storage capacity was already in 1976 assessed to have been reduced to about 800 million $m^3$, due to heavy siltation coming from the Ethiopian highlands with the Atbara. Over 90% of the water in the seasonal Atbara river flows past the scheme from July to the end of September, during which time the dam is to be filled up for the whole annual irrigation amount (Thornton and Wynn 1965). The water is distributed to the project area through a main canal designed to take 100 $m^3/s$ and then further through a network of smaller feeder and irrigation canals. The scheme area and the framed reasearch areas are shown in Figure 3 in Annex C.

About 50,000 Nubians (some 7,000 families) were resettled in the scheme in either pre-built brick houses constructed in 25 villages in the scheme area, or then in New Halfa town which was also established on the Butana plain. Each of the Nubian villages consisted of about 250 – 300 families resettled according to their former home villages in the Wadi Halfa area. The scheme had originally 22,000 tenant households and, apart from the Nubians, the remaining 13,000 tenants were chosen from among the local population which had been living mainly as pastoralists permanently or semi-permanently in the area (Drupsteen et al. 1989a; Drupsteen et al. 1989b). The tenant households received three fields of 5 feddans each on which they were to grow cotton, groundnuts and sorghum in rotation. Freehold land for vegetable-growing was also given, based on how much farmland the households had owned in the Wadi Halfa area.

Many of the Nubians had only little or no previous experience from farming upon arrival in New Halfa (Agrar und Hydrotechnik 1978; WB 1992;). The rural population was distributed in the 25 scheme villages and many so called hut camps where the landless migrants and labourers from other parts of Sudan had later settled. The landless population has been grouping itself into the eastern Sudanese (so called Arabs) and the western Sudanese (so called landless), who do not mix much with each other even if they live in the same camps. The reason for segregation was not completely clear, but the western Sudanese landless had farming traditions, while the eastern Sudanese landless mainly had pastoralist traditions (Mageed et al. 2001).

Prosopis was first introduced to the New Halfa Scheme to form a living fence around a trial site for the introduction of new crop species and varieties. In the 1980s prosopis began to spread on a larger scale in the surroundings, invading all kinds of land: fields, canal banks, road sides and village expansion sites. In March 2001 it was estimated that prosopis had invaded 29% of the scheme area, excluding the sugar factory estate lands. The prosopis invasion was in 2003 - 2004 heavier in the south and decreased gradually to the north of the scheme. Almost all land south of and around New Halfa town had become invaded, while further north there were in 2004 so far only small patches of invading prosopis adjacent to a few villages. The sugar cane plantations to the north of New Halfa town in the central parts of the scheme were owned and monitored by the sugar factory management, and these fields had been kept clean from prosopis invasion through early detection and uprooting.

According to Mageed et al. (2001), prosopis had caused problems in the New Halfa Scheme mainly through: (a) plugging the canals of the irrigation networks (1,200 km out of total of 4,082 km); (b) invasion of agricultural land, making crop production difficult or sometimes almost impossible; (c) invasion of freehold lands and villages; (d) large bushes closing sand roads from both sides of the roads and constraining mobility; and (e) thorn injuries on people and the livestock.

The irrigation system in New Halfa is mainly based on gravity, with some support from motorized pumps. The irrigation canal networks were designed with the Gezira Irrigation Scheme as a model. The system has one main canal and branches of major and minor canals that feed the field outlet pipes (FOPs). Each FOP feeds a ditch, “abu ishrin” (Arabic name for the size of the canal) that itself feeds a number of 280 m long secondary ditches, “abu sitta”, that lay 75 m apart, parallel to the minor canal and to the basins of 5 feddan (= 1 “hawasha” or 2.1 ha) of agricultural fields for which they form the upstream and downstream borders. Originally the irrigation water entered the scheme canals only during day-time, but, due to large-scale siltation problems in the Khasm-al-Girba dam, the scheme management has allowed substantial amounts of stagnant water to be stored in the scheme canals. This has created serious problems with weeds and siltation (Ibrahim et al. 2002).

**The Gandato Irrigation Scheme.** This scheme is one of the tens of medium-size irrigation schemes which have been established along the White Nile and the main River Nile. It lies about 120 km north of Khartoum and 1 – 25 km south of Shendi on the eastern river bank in River Nile State. It could be considered as a representative scheme for the current research purposes both for its size and for the challenges it faced in terms of sand encroachment, irrigation failures and prosopis invasion. The framed area in the Gandato Scheme is shown in Figure 4 in Annex C.

The first small scheme was established in 1911 by local farmers, who built ox-driven wheels by the river to pump water to their fields. In 1917 – 1919, in the aftermath of World War I, the British colonial administration saw the opportunity to grow cotton in this area on a larger scale, and established a proper irrigation scheme under the Egyptian Department of Agriculture, using four steam engines confiscated from German steamships for pumping of water. Besides cotton, crops such as onions, okra, sorghum, wheat and maize were also grown. In the late 1930s citrus and mango trees were introduced. In 1966 the centralized crop rotation system was abolished and the Egyptian broad bean was also introduced to the scheme.

In 1992 the scheme received new irrigation pumps, which substituted the old steam engines. In 1985-1995, the SOS Sahel Shelterbelt Project established in the Shendi region numerous shelterbelts with prosopis along either side of the Nile, and the Gandato scheme was part of this project. All the current shelterbelts that protect the villages in the framed research area were established by the SOS Sahel project, and several of the FNC foresters in Shendi were in those days employed by the project before the Eradication Decree caused a full stop and ban on the prosopis planting activities. Even before 1985 there were some few prosopis trees in Gandato, which the farmers had planted by themselves using seeds from prosopis shelterbelt stands elsewhere in River Nile State.

### 4.3. Specific methodologies for the household income studies

#### 4.3.1. The household survey approach

The main purpose with the selection of the household survey method was to enable the collection of sufficient and good-quality household economic information. This information was needed for understanding the economic decision-making situation of the households and the ways in which various population groups differed from each other in terms of their overall livelihoods as well as in their encounters with prosopis. Direct contact with household heads and other household members resulted, apart from the interview data, also in a deeper understanding of people’s lives. Interview sessions were held in villages or camps in houses, huts, Koran schools, and some other local public facilities while eating the local food and drinking the local tea or coffee. In each hut camp the numbers of huts and fences around homesteads and fields were assessed and some charcoal burning sites were visited. The ways of keeping and feeding the livestock were observed and discussed while walking around. Many side comments outside the questionnaire protocol were also useful.

The interviewees were selected on random basis after a first stratification of interviews per village and camp. It was not only the household heads who were interviewed; many times it was the wife and sometimes a son who answered the questions. The interviewed household members seemed to know very well everything that concerned their expenses in relation to agricultural operations, livestock or anything else in the household’s own economy. For many households the actual annual income could be fairly well pinpointed, but for some households it appeared first that no income source could be identified. However, every household turned out to have some kind of income, which could be identified when the answers were carefully checked and more questions outside the questionnaire were asked.

Representatives from other households were usually present, and these other persons could many times assist an old or shy person to remember something that otherwise would not have been properly communicated. These outsiders in a given interview were thus sometimes also acting as triangulation points by assisting in the checking of the validity of the answers and saving much research time. Questions were split into smaller pieces of information with an idea of making it more difficult for the other villagers to make a full account of another household's economy. Each piece of information was then afterwards entered into the combined database.

Often the whole group of people was at the end of the session given group questions covering the whole village. The final answer could then be given jointly or as an opinion of someone who had specific knowledge on the particular issue. As the questions were related to the economic facts and not to personal perceptions, the group sessions yielded much information that supported the analyses.

In some works by other researchers, for instance, Campbell et al. (1997) there have been attempts to subtract the household's own labour from the market prices of its non-wood products. Calculations in this study were based on net incomes, which is the total absolute income exclusive of cash and subsistence inputs, and thus also exclusive of the household's own labour, following the approach of Ellis (2000) and Cavendish (2002).

### 4.3.2. Collection of data on household and population group economy

**The New Halfa research site.** Interviews in the New Halfa Scheme were conducted mainly in June and July of 2003 and confined to the middle parts of Section Debeira in the southern parts of the Scheme, where Nubians originally from Wadi Halfa formed the tenant population, inhabiting five villages in the framed research area. From each tenant village six households were interviewed on random basis. Totally 30 tenant household interviews were carried out. The size of the framed area was approximately 136 $km^2$.

Apart from the tenants there were also immigrants from western and central parts of Sudan who had arrived mainly due to the droughts in the 1960s, 1970s and 1980s and, later, due to low income opportunities in White Nile and Gezira States. These other immigrants of various ethnic backgrounds, from the (south)-western and central parts of Sudan, formed the western Sudanese landless population group in the research area. Another similar population group of less educated local people, from an area between Ed Damer town in the north and Kassala town in the south along the Atbara River, formed the eastern Sudanese landless population group. From both groups 30 households were interviewed respectively. These households were selected in the hut camps on random basis once an initial share of interviews had been decided for each camp. Many of the hut camps for the landless had begun to merge, although the western and the eastern Sudanese landless groups had still their own communities within the same overall camps.

The fourth population group in the framed area consisted of the nomadic or semi-nomadic people who were not stationary in the framed area. These people stayed in the New Halfa Scheme area for about seven months annually and migrated with their livestock through the framed area back and forth on their way to the plains near Kassala in the rainy season. Without an account on how long they stayed in the framed area, 25 nomadic or semi-nomadic households were interviewed to understand their lifestyle, their welfare situation and the role of prosopis for them.

The household questionnaire was combined with a group questionnaire which contained questions that a group of people could answer together to save time and effort, and to keep up interest for the questions. In this way the overall situation of the villages was also assessed. In June 2004, the researcher visited again the New Halfa Irrigation Scheme to conduct a few additional interviews on questions that had remained unclear during the 2003 interviews and to expand the household interview data with a few more full-fledged interviews. Various professional experts such as representatives of the scheme management staff, agricultural researchers, foresters, medical doctors, veterinarians and town administrators etc., were also interviewed in New Halfa during the visits, so as to compile a comprehensive set of information for the research. In June 2004, a visit to the northern parts of the New Halfa Scheme was also conducted, to enable collection of data from a comparable site where there had so far been no prosopis invasion. In each of eight villages one household and one group interview was conducted. The main reason was to identify differences in income opportunities and health impacts between these villages and the primary framed research area.

**The Gandato Scheme research site.** In August 2003 the researcher visited briefly the Shendi area again and the exact research site was framed south of the town on the eastern bank of the Nile after reconnaissance trips on both sides of the river. Both north and south of Shendi some few household interviews were conducted in several villages to get a grasp of the situation. Afterwards the data were coarsely analyzed and some improvements to the questionnaire for the Gandato Scheme were made. The main data collection, consisting of 70 household interviews, was conducted in the framed area of the Gandato Irrigation Scheme south of Shendi in January 2004. The size of the framed area was in total 29.5 $km^2$. Additionally, two interviews were also carried out with households resettled in Shendi town; they had been forced to leave the research area villages due to sand invasion on their houses and homesteads. Furthermore, four additional households were interviewed, two in Al Abdutab village on the west side of the Nile and another two in Taragma village north of Shendi. These villages had been severely invaded by sand until prosopis shelterbelts had been established outside the villages in the early 1990s. Several professional experts such as agricultural researchers, foresters, medical doctors, scheme management staff, property agents, town administrators and merchants in Shendi were further interviewed to elaborate on the information.

From the framed area in the Gandato Irrigation Scheme a wealth of various data was collected from the start which also considered the needs of the subsequent TEV study. All 70 households interviewed in the framed area were combined into one set of data from which the household economies of the area were analyzed. The household survey focused from the start also on collection of a sufficient amount of information covering the following aspects:

- Sand-invaded households vs. households protected by prosopis;
- Sand invasion frontline households vs. field-side households;
- Crop cultivation field units in protected vs. unprotected fields;
- Differences between various parts of the villages, further elaborated in group interviews.

Additional supporting data and information were also collected. Soil samples were taken next to the Al Figaiga village representing a bare land site, a 20-year-old prosopis stand, and at a 36-year-old mango orchard, respectively. These samples were analyzed by the Agricultural Research Corporation Soil Analysis Laboratory in Wad Medani. Additional soil analysis results from 2002 were also retrieved for an area in the vicinity of the framed research site which had been suggested as a potential location of a new private irrigation scheme (Doka et al. 2003).

In May 2005, additionally four resettled household heads originating from River Nile State (although not from the Shendi area) were interviewed in Khartoum North. These households had left their rural villages due to sand invasion and settled in the outskirts of Khartoum North. The aim was to know the life situation of the households in Khartoum after resettlement and the extent to which they were still socially linked to their former home villages. In Khartoum other discussions were also held and information was collected from professionals, such as ministerial and Forests

National Corporation (FNC) staff, agricultural and forestry researchers, housing property agents in the suburbs of Khartoum North, Bank of Sudan staff, and NGO representatives. Libraries of IUCN, WHO, FAO and UNDP were also utilized for supporting information retrieval.

**Selection of time frame for the household surveys.** Both in the New Halfa Irrigation Scheme and in the Gandato Irrigation Scheme the main cropping period starts in the second half of June. Therefore a decision was made to assess the annual household incomes as well as to conduct the financial analyses for a financial year from mid-June 2002 to mid-June 2003. The analyses were related to one year only due to several reasons. Firstly, almost all the data were based on personal interviews and required that these persons remembered all their financial transactions. Focusing on the latest harvest and its operational costs was therefore easier than to distinguish between different years and their various production constraints. Secondly, the whole financial analysis of households economies would be too complicated to sort out for a longer period. Thirdly, a household analysis was challenging enough even without taking the inflation into consideration. Fourthly, the main idea behind the household analysis was to clarify the interaction between prosopis and people, which could be distinguished within a one-year economic analysis.

**Crop prices and operational expenses utilized in the analyses.** Farmers in the Gandato Scheme area stated in each case their respective harvested amount of crops and sales prices. The data from farmers in the New Halfa scheme villages, collected in 2003, did not always include all specific information, as these farmers were interviewed first and the questionnaire and the routines were at the time not fully developed. Some of these shortcomings were in June 2004 corrected by collecting new data in each village and camp in one group and one household interview, respectively, to set the production levels and prices right also for the previously made interviews. In this way, the earlier data collected could be elaborated and fully utilized.

The New Halfa Scheme management staff provided also their own price and production figures, which could to some extent be used after careful checking, as the official scheme prices tended to be rather high (apparently at least partly representing the reselling prices). However, the selling price of most crops varied also much during a year. In 2002 the scheme management's official statistics indicated an average monthly farm gate selling price for sorghum in the range of 2,868 ± 211 SD per sack and for groundnuts a range of 1,350 ± 368 SD per sack, respectively. Discrepancies between the official generalized scheme data and the own specific data collected by the researcher could probably also be explained by the fact that particularly the poorer households normally had to sell directly after the harvest when the prices were extremely low due to a momentary excess supply. Some of the poorest households even had to sell their crops to middle-men in advance before the harvest for yet lower prices, due to immediate cash needs.

In the New Halfa Scheme the Nubian tenant farmers studied grew, rotation-wise, 5 feddans of cotton, groundnuts and sorghum, respectively, on their scheme land, and the households had additional freehold land based on the amount of farmland each household had owned back in the Wadi Halfa area. For the households interviewed this freehold land ranged between zero and 25 feddans per household. On the freehold land, various crops could be grown, according to the farmer's own choice, and in many cases these crops could provide substantially higher profits than the scheme land crops. Tenant farmers needed hired farm labour, as very few of them could manage all cultivation operations with their own family labour only. In the framed research area in New Halfa, prosopis had invaded almost all uncultivated land and the fields needed in most cases regular weeding. This increased substantially the labour requirements per feddan of crop cultivation. This labour shortage had often been solved through the renting out or sharing parts of the scheme land or freehold land with the western or eastern Sudanese landless households.

The profitability of the renting or sharing of fields varied from case to case, but normally full renting gave the best profit to the landless farmer. Renting contracts were not so easy to get, though, and landless farmers were normally hard up with cash at the time when crop operations should be carried out and expenses paid. Renting land meant paying of a rent, after which the land user was cultivating the land and receiving the profit totally by himself. Sharing was done either with a tenant and a share cropper dividing all operational costs and harvest gross margins in equal parts, or by the share cropper household cultivating the land and paying all the operational costs and eventually giving 20% of the total crop income to the tenant landlord. In the latter case the tenant landlord could sometimes receive the total actual cash profit of the whole cultivation. Additionally, the prosopis-invaded fields were the ones that the tenants were ready to share or rent out first, as difficult weeding was needed on them. Only sorghum and groundnut fields were shared or rented out, as the cotton fields were considered by the tenants to be too valuable to be shared. The cotton fields were also properly weeded during the preceding year's cropping with sorghum or groundnuts.

In the Gandato Scheme south of Shendi town, the prevailing overall research constellation was more organized from an analysis point of view, as the population was more homogenous. However, the scheme did not have anymore a centralized cultivation system or specific schemeland crops, in contrast to the New Halfa Scheme case. There were now only tenant farmers who produced various kinds of crops on freehold lands, and then there were farm labour and even some households which rented irrigated farmland; these fields were all operated according to fairly stable annual operation costs. In three household interviews from two of the villages it was stated by individual farmers that all operational costs for a farmer of one feddan of onion and one feddan of beans would be around 200,000 SD. This information seemed accurate, according to the pieces of detailed operation cost estimates collected from the various farmers, and therefore it was used as calibration for scaling the expected annual operation costs. These became, per feddan, in this way for onion 151,000 SD, for beans 50,000 SD, for fodder 67,000 SD and for fruit production 61,000 SD. For each household's crop production such an expected value was first calculated based on the above figures, and then the calculations were tailor-made on the basis of the constraints and opportunities which each specific farmer had mentioned in the interview in respect to his personal operational costs. The farm labour cost required for weeding of prosopis in the fields was calculated as half the amount paid to labourers for all farmland weeding operations. This excluded, of course, the households' own weeding labour, but analyses did not include other own labour costs of the households either.

**Incorporation of livestock incomes and expenses.** The livestock owned by households was taken into account only through subsistence consumption and sales in the financial year 2002 – 2003, as the livestock can be considered as risk capital that may or may not support the households financially. Livestock of various kinds had died of diseases or been stolen every year, particularly in New Halfa but sometimes also in the Gandato area. For comparison, in case an animal only feeds on commercial fodder and there is no milk production and sale, the animals would in one month cost more than could be received from selling the whole animal.

For each household the amount of fodder needed for livestock (livestock fodder units) was calculated. The average feed intake was calculated by asking groups of farmers in all villages about each kind of livestock's daily fodder needs. This led for each household interviewed to a hypothetical commercial total annual fodder cost figure. This was estimated based on daily and monthly figures given by the households. From such a hypothetical annual figure the actual annual fodder costs and subsistence fodder use was then subtracted as stated by each farmer. The remaining unaccounted part of the hypothetical annual fodder cost was then seen as covered by free-grazing opportunities, which could be divided between prosopis and other free-grazing forage.

**Calculation of free-grazing forage shares.** Reference literature was consulted in order to estimate the share of prosopis forage from the remaining unaccounted feed intake. The most useful referenced findings are presented below; based on these the various results were synthesized.

Abdelgaabar (1986a, b) conducted five highly useful comparative feeding trials with goats and sheep using pods of the local variety of prosopis. In the first trial he divided 48 five-month-old desert goat males into four groups of 12 animals which he fed for seventy days with 100%, 85%, 70% or 55% of prosopis pods, with the remaining portion of the fodder intake consisting of varying amounts of cottonseed cake and wheat bran. The animals were weighed before starting the trial and then again every two weeks and at the end of the trial before slaughtering. The trial showed that the sheep fed with 100% or 85% of prosopis pods in the fodder had lost weight, while animals fed with 70% or 55% prosopis had gained weight. The carcasses were further analyzed, and the results showed that a feed intake with 70% prosopis or less kept the goats in almost the same fitness throughout the study, while a feed-intake with 85% or more of prosopis pods in the fodder reduced the animal fat percentage substantially.

A second similar study was conducted with eight adult male goats divided into two groups, with one group only receiving prosopis pods and the other 55% prosopis pods, 30% wheat bran, and 15% cotton seed-cake in the fodder. The study showed that the goats feeding entirely on prosopis pods managed well in respect to their metabolism, although the digestibility was slightly lower than in the mixed fodder case.

The same author conducted a third prosopis pod feeding trial with 24 yearling desert sheep. After an initial period of two weeks on alfalfa and ground sorghum grain the sheep were divided into four groups with comparatively equal total body weight. Three groups (A, B and C) were fed intact prosopis pods and the fourth group (D) was fed with 44% sorghum grain, 29% *Aristida funiculata* (humra in Arabic), 25% cotton seed-cake and 2% mineral and vitamin mixture. The sheep in groups A, B, and C started to die in the 12$^{th}$ and 13$^{th}$ week, and after the slaughtering the reason was found to be ruminal impaction due to improperly digested prosopis pods, which led to to the production of bacterial lactic acid in excessive amounts resulting in severe acidocis and dehydration. The sheep in groups A, B, and C lost 14% of body weight during the 13 weeks, while the sheep in group D gained 54% more body weight during the feeding trial.

A fourth feeding trial was also performed with 24 yearling sheep in which the animals were divided into three groups that all got for ten weeks an intake of 58% intact prosopis pods and 2% minerals and vitamins as well as a variable amount of molasses and karkadeh (*Hibiscus* spp.) stems. The three feed categories each gave the same nutrition level or 12.0 MJ/kg of dry matter, but in variable composition. The sheep that got more molasses gained weight slightly better, but the results showed that prosopis pods can form a suitable feed intake provided it is supplemented with energy and protein. Bhatta et al. (2005) came to similar conclusions in another sheep feeding trial in semi-arid India.

A fifth study by Abdelgaabar (1986b) determined the approximate composition, in the local Sudanese variety of prosopis, of intact pods (crushed), extracted seeds (crushed) and leaves. The seeds had the highest protein content (32.5%) followed by the leaves (14.8%), while the whole pods had the lowest protein content (12.5%). The contents of crude fibre and nitrogen-free extracts were high in all categories and varied between 12.2 to 27.2% and 47.4 to 53.3%, respectively, in seeds, leaves and whole pods. The level of major elements and trace elements was mostly adequate in all three categories for calcium, phosphorus, potassium, magnesium and copper. The levels of sodium and zinc were too low in all categories. The study concluded that green leaves of prosopis are unpalatable to all kinds of domestic livestock, except for camels.

Chopra (2002) analyzed in India the approximate compositions of seeds and pod hulls of *P. juliflora* from 18 different sites and found that there are significant variations. Crude protein varied in the range of 30.7 to 36.2% in seeds and 6.7 to 10.7% in hulls. The ether extract in seeds and hulls ranged from 2.4 to 5.1% and 1.5 to 2.7% respectively. The crude fibre in seeds varied from 4.6 to 8.0%, whereas in hulls it varied from 22.1 to 31.0%. It was also concluded that variations in the chemical composition do exist in seed and hull portions of *P. juliflora* pods based on sites. According to Pasiecznik et al. (2001) there is a similar variation in the composition of prosopis leaves, which is further accentuated in differences between young and old leaves.

Prosopis pods in Sudan have a low sugar content of only 13 to 20% (Pasiecznik et al. 2001) in comparison with many South and North American varieties used in the food industry which contain from 35% up to even 59% sucrose (cf. Estévez et al. 2004). The unripe pods in Sudan are bitter and not preferred as fodder. Pods mature between December and June and provide therefore needed fodder during the peak dry season (Siddig 1986; Bristow 1996; Felker 2003). Shiferaw et al. (2004) reported from Ethiopia that one kg of goat and cattle droppings contained, on average, 760 and 2,833 prosopis seeds, respectively, thus suggesting that cattle are the primary pod-eaters and thus dispersers of prosopis seeds.

ICRAF researchers (Kitalyi et al. 2005) have also studied grasses, legumes and tree leaves used to feed livestock. Fibre is an important component of ruminant feed because it is necessary for the normal functioning of the rumen, and a low fibre content in the feed also decreases the fat in milk. Feeds rich in protein, such as those from trees and shrubs (i.e. leaf forage), can form an important part of the feed intake of livestock. Dairy animals also require minerals, nutrients and vitamins for their bodies to function properly and particularly calcium to develop strong bones and joints. Cattle further require substantial amounts of water to be healthy, to grow, and to produce adequate amounts of milk. Fresh leaves can provide most of the nutrients and part of the water needed. However, the forage from some tree species also has natural substances in leaves which are toxic and even anti-nutritive to livestock. Toxic substances in forage will lower the voluntary intake and sometimes make it indigestible. The concentration of toxic substances changes with the stage of plant growth, which explains why livestock sometimes refuse and sometimes eat tree leaves (cf. Pasiecznik et al. 2001).

Browsers have the ability to consume a variety of forage that cannot be eaten by other animals. Some types of livestock develop microbial populations in their rumen that can neutralize anti-nutritive compounds. Anti-nutritive compounds are found in leguminous trees such as, for instance, *Leucaena leucocephala*, which contains mimosine. Kakengi et al. (2001) found that *L. leucocephala* leaf meal given as supplement to a cattle diet of cotton seed hulls increased both the body weight and milk amount. Other studies have revealed that at least sheep and goats can eat also prosopis leaves, particularly young tender leaves which contain less anti-nutritive substances and tannins. The level of these substances will diminish from leaves and young branches in a few days after their being cut from a tree and thereby the leaf debris is potentially good fodder for livestock (Pasiecznik et al. 2001; Siddig, 1986). Personal observations in the field also confirmed that sheep and goats nibble on prosopis leaves from trees, and many villagers in both the New Halfa and the Gandatou Irrigation Schemes stated that domestic animals eat both pods and to some extent leaves of prosopis, and further, that very little grass existed for grazing even during parts of rain season (cf. ElRahman 1991; Bristow 1996).

Free-grazing livestock also ingest some soil while grazing. A study from New Zealand estimated the intake to be about 4.5% of soil for free-grazing sheep. During the dry season, when forage is sparse, the intake of soil may even go up to 18% of the total forage intake. The New Zealand study estimated further, that a 500-kg all-year free-grazing dairy cow could eat 900g/day of soil, when the total dry matter intake was 15 kg/day (Beyer and Fries 2003).

All the above mentioned trials, studies and own field observations on particularly the poorer households' livestock situation (these particular livestock had many times only free-grazing forage to eat) led to a rational deduction that the livestock at both research sites fed on, apart from the household's own cultivated and purchased fodder, also an extensive amount of free-grazing forage, which annually consisted of around 75% prosopis and 25% other vegetation and soil. Prosopis constituted almost the only fresh free-grazing forage in the drier periods of the year, and therefore the farmers provided some alfalfa, sorghum or groundnut shells to enable the livestock a possibility to mix the prosopis forage and fodder in the rumen. In the rainy season there was for some months grass available, although overgrazing often prevented grasses from maturing. Particularly in New Halfa the livestock was not gaining weight, which would indicate a slightly higher degree of prosopis in the diet than in the Gandato Scheme area. Some farmers allowed their livestock to graze in their fields for a given period which was adjusted according to the individual household's economic calculations. In the Gandato Scheme the commercial fodder was alfalfa with some additional sorghum in Wad Killian, and the prices were stable, while in the New Halfa Scheme the purchased fodder varied more in type and price among the various villages and camps, which made calculations tedious.

**Incorporation of milk and meat incomes.** The amount of milk from the households' own livestock was calculated on the basis of the number of milking animals and the amount of milk that the average cows, goats, sheep and camels produced. The data from each village and camp were collected in group interviews and from several individual households and then combined with the data on household livestock numbers. Other studies such as that by Ayalew et al. (2001) have concluded, based on research from Ethiopia, that the subsistence income from milk and meat may be an important part of the household income.

In New Halfa the meat consumption was calculated from village group interview data on animals sold and on the size of animals combined with butchers' information on how many animals had been slaughtered weekly, as well as from the meat selling prices. Villagers also estimated how much meat they purchased from the village butcher and consumed within the households. For the Gandato framed area, such information was left out, as the Shendi town was quite near to the area and several butchers operated particularly in the Al Hosh village; thereby it was not possible to control the meat source or average amounts used in households. Many labourers from Wad Killian could also purchase meat in Shendi, where they worked on daily basis.

**Calculation of labour salaries and incomes.** The monthly income for many unskilled and skilled labour occupations available for households was the same for all persons working within each respective occupation in the framed areas, and the data on salaries for each labour category were derived from either the person himself/herself or from group interviews in each village. Also net merchant incomes (including gross sales, production costs, taxes and permits) were retrieved directly from the household or group interviews. For a few kinds of specific businesses other villagers were later asked to provide information if the household head had not been willing to give it. The amounts of private cash remittances in a village were also fairly well known.

**Calculation of prosopis wood and NWFP incomes and expenses.** All amounts and price data related to collection and purchase of prosopis wood and purchase of charcoal and cooking gas were retrieved directly in the household interviews both in Gandato and in New Halfa areas. In the Shendi area all charcoal was transported from other parts of Sudan (mainly from the Rahad and the New Halfa Schemes). In New Halfa, prosopis cutters and farmers gave their estimates on the average monthly incomes from cutting, weeding and charcoaling, as well as some estimates on how long the clearing of some specific measurable prosopis stands had taken them. The group interviews in each village in New Halfa gave estimates on the amount of charcoal produced per month in terms of lorry loads and on how many sacks were sold monthly in the neighbouring villages. Prosopis fuelwood and poles were either used in the villages or sold locally. The two main prosopis merchants were also interviewed, and they stated the number of truck loads sold from the framed research area. The average lorry and truck load of charcoal sacks was also quantified.

The length of fencing installed made with thorny prosopis branches was also assessed in the villages and camps. The financial department staff of the New Halfa Scheme provided their calculated cost figure on barbed wire fencing. In 2003 such a two-metre high fence cost 100,000 dinars per 110 m length. The barbed wire fence would last for some 25 years, while the fencing with prosopis was estimated to need full renewal every five years.

**Calculation of the economic burden from sand invasion.** The main household survey conducted in the Gandato scheme framed area included questions on sand invasion in relation to each specific household. Households were interviewed on where their house was located in the village, the type of house, how much annual rebuilding the household would need, how much sand excavation the household conducted during the previous year, how many social visits the household members had made to Khartoum or Shendi, and on the expenses for such visits. For the social visits the households were further asked whether it was the trip itself or the meeting of their friends and relatives that was important to them, in order to separate the social duty from a potential pleasure of just travelling to Khartoum or Shendi.

While some of the household interviews were conducted during the first IEE reconnaissance mission to the area, most of the sand invasion questions and answers were lacking for the five pilot households interviewed in Al Hosh in July 2003. This was solved through the calculation of a correlation between the Al Hosh households' net annual cash income and the social visits, where the former was determined as the annual cash income subtracted by the known main household expenses (these were costs for water, electricity, telephone, school fees and daily transportation). As households had social visits to either Khartoum or Shendi or to both places, it was further necessary to count all social visits as one kind of visits for this correlation. This was done by recalculation of a Shendi visit as corresponding to one fourth of a Khartoum visit, based on the actual travel expenses. Household interviews from the Hassania part of Al Hosh were excluded from the correlation, as it was known that no households in this part of Al Hosh make any sand invasion-induced social visits. The reason for this was that no households from this sub-village had resettled, according to an answer in the group interview from Hassania.

**Surveys on health impacts of prosopis.** During the last decade there has been a global polemic discussion on the wisdom of planting trees near irrigation canals inside agricultural irrigation schemes, as there is a high risk of increasing the impact of water-borne diseases such as malaria and schistosomiasis (bilharzia) on household health, income generation and productivity (Listorti and Doumani 2001; Amacher et al. 2004). Conditions particularly in the New Halfa Irrigation Scheme fulfilled all criteria for providing breeding grounds for vector-borne water-related diseases (cf. Prüss et al. 2002). Prosopis is likely, as part of the unmanaged vegetation in the Scheme, to directly impact on the above-mentioned diseases in the framed research area. Annex A presents some facts about malaria in Sudan and its perceived impacts on the local and national economy.

A few households in each village were also interviewed for clarifying how many members of the household contracted malaria or schistosomiasis, on a monthly basis, during the rainy and dry seasons, respectively. Group interviews yielded further information on incidences of thorn injuries (sometimes even leading to amputations), snake bites and scorpion stings. All health information was requested separately for the previous year and for a period of approximately ten years earlier for a coarse trend estimation. Additional health information was retrieved from local doctors, veterinarians and the village group interviews. Other known costs such as water, electricity and school costs were also directly obtained from interviews.

## 4.4. Specific methodologies for the prosopis TEV study in the Gandato Scheme

### 4.4.1. Methods for the valuation work

The screening process went forward as shown in Figure 2, through analyzing the household income structure and other collected data and by conducting a literature review. Unimportant and non-existent benefits and costs were filtered out, and the remaining ones were gradually separated or grouped under new, more useful analysis headings that indicated the benefits analyzed together in one value entity, so as to avoid overlapping in the monetization process. Some remaining impacts identified at the framed research sites were qualitatively assessed and described but left without monetizing. The identified benefits and costs included in the TEV and the selected valuation techniques used were grouped as shown in Figure 5.

The situation in New Halfa was too complex to be valuated and monetized as a TEV study within reasonable effort. It was thus analyzed only using the household surveys and some specific studies that determined the magnitudes of benefits and costs. Some standardized income measures and subsequent income comparisons are presented in sub-chapters 5.1.2. and 5.2.3.

The TEV exercise concentrated on the impacts of prosopis in the framed research area in part of the Gandato Irrigation Scheme south of Shendi town. In particular, the focus was on the externalities, public goods and other impacts prosopis posed for the villages of Al Hosh, Dueimat, Al Figaiga, Tundub and Wad Killian as whole communities. To clearly distinguish the overall comprehensive prosopis impacts, three different scenarios were investigated. The first scenario represented the current reality with its major market failures (*Scenario A*), while the second one represented a hypothetical situation with all prosopis absent from the framed research area and the relevant externalities of such a situation (*Scenario B*). These two scenarios were developed in parallel and then eventually the latter was monetarily subtracted from the former as shown in Table 32 in Annex C, in accordance with the equation used by Pierce and presented on page 37. Based on these two scenarios a third hypothetical scenario was constructed for comparison and it represented a situation where prosopis would be growing in the whole framed buffer zone area (*Scenario C*); this was derived from the calculations of the other two scenarios with some additional analyses.

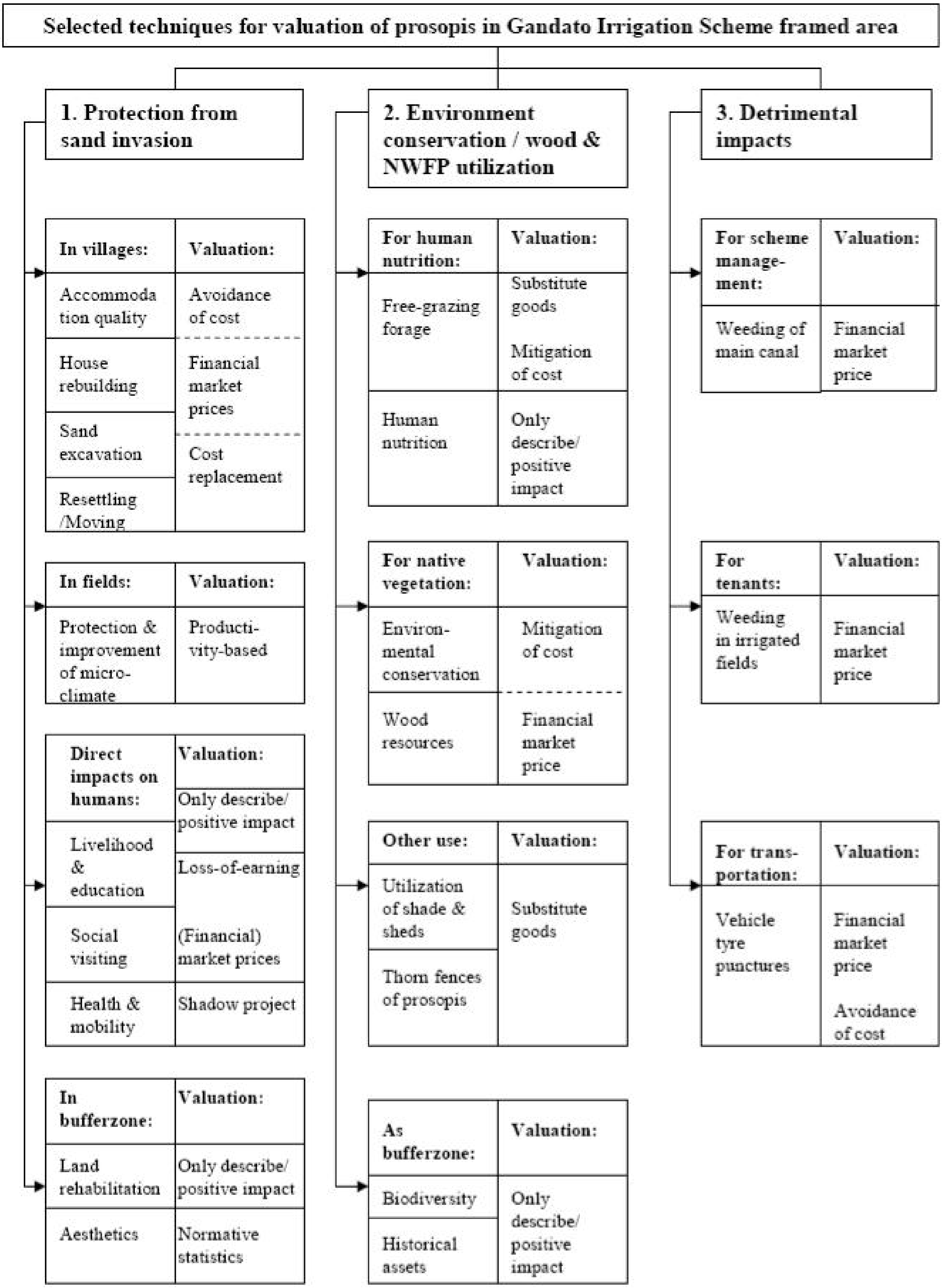


Figure 5. Identified benefits and social costs of prosopis included in the TEV with the corresponding selected valuation techniques used in the study.

The household interviews were supported by satellite image work, as no reliable recent map existed at the outset of the data collection. A hand-drawn coarse map from 1986 showing the Gandato Irrigation Scheme fields only (with neither the river nor the villages indicated) existed, but it lacked proper scales and fixed points, which made its use cumbersome. As most of the area between the fields and the railway had an elevation difference of only some few metres and the villages inside the 3 - 5 m tall thickets of prosopis were also low, it was difficult to get an overview of the framed area at the site. Landsat satellite images from January 2004, December 2002, December 1987, and November 1972 were purchased for the framed area with a resolution 15x15 m. A purchase of a commercial satellite image with finer resolution was considered too expensive, and archived discounted images were not available for this specific area. The acquired images had not enough resolution to distinguish the villages from the surrounding environments, but this problem was solved by taking 38 GPS points from the framed area, whereby all the villages obtained a GPS point from four sides, with some additional landmarks also pinpointed. In this way the satellite images became better readable as maps and could be used as the mapping tool needed in some of the analyses described below.

Already during the collection of interview data in the field and later as seen from satellite images from 1987 and 1972 it became clear that the Nile is changing its course in the area from time to time. After a map of the Gandato Irrigation Scheme was hand-drawn in 1986, the river had moved to parts of the framed area fields in the Al Figaiga, Dueimat and the southwest corner of Al Hosh; this had had an impact on the main canal network, which had then been partly moved and reconstructed further up on scheme land. Reconstructions in the canal network and field layouts had thus been done, but these changes were barely distinguishable on the Landsat satellite image. In combination with field observations the satellite image was, however, sufficient for the analyses.

During the data collection, various Sudanese and foreign research articles were encountered dealing with the area and with related cases in Sudan and the Sahel region. These external referenced results are presented both in the methodology and in the results chapters, as part of the validation of the financial analysis conducted in this study.

### 4.4.2. Approach for inclusion of Tundub in the TEV study

Tundub is the Arabic name of *Capparis decidua*, which has in the past been the main native tree species in the framed buffer zone area. There was still one dense and tall stand of this species next to the Tundub village. This village lies almost in the exact middle of the framed buffer zone area between Al Figaiga, Dueimat, Banat al Hamda (part of Al Hosh) as well as Wad Killian. It appears to have been established after the Gandato Scheme was established and therefore its inhabitants have had no share in the scheme. As its population mainly consists of the Gaalian and Shaigyan ethnic groups, it is likely that the population consists of decendants of the inhabitants of the Gandato Scheme tenant villages such as Al Figaiga, Dueimat and Al Hosh. Today there are also the Ababdan, ZuAdab and some other ethnic groups with pastoralist background. Tundub is the hospital site of the populations from Al Figaiga, Dueimat, Wad Killian, Abduiab, and Bedr Kubra (the two latter villages being situated across the Nile) as well as for nomads visiting the area. The hospital was planned to cover the needs of totally some 1,000 households from the above mentioned villages. Tundub is currently inhabited by about 75 households, of which only a few may have obtained irrigated fields inherited from a parent or parent-in-law or through renting of fields in the scheme.

During the time of the household surveys and other data collection in the Gandato scheme the research focus was on the differences between villages with and without prosopis protection. As

Tundub was seen as a compromise between these two kinds of village types, it was left out of the household economic survey as an unclear case of prosopis impact on household economies. However, due to the fact that the village is in the middle of the framed area it could not be left out from the externality analyses which eventually were developed after the household survey data collection was conducted in the Gandato area. Due to the above-mentioned circumstances only one full household interview was conducted in Tundub. This gap in data collection could, however, be rectified satisfactorily; partly because some other interviews of professionals like a doctor, a school teacher and a bakery worker were conducted in the village. Based on this gathered information it was possible to reconstruct average proxies for household economies for the Tundub villagers by profiling adjacent households in Al Figaiga, Dueimat, Al Hosh and Wad Killian for the purpose. A total of 26 such suitable households were found in the above listed adjacent villages which fitted the non-tenant profile, and these were combined into one new data set representing the average household income proxy for Tundub in the TEV study.

Various other observations could also be made in Tundub. For instance, one household had 15 cows held in a walled-in area of 500 $m^2$ with prosopis trees 5.5 m tall providing shade for the animals and with a small lot of irrigated fodder next to the village in the prosopis buffer zone. This field was irrigated by a well in the neighbourhood. A few medical doctors working at the hospital lived in Tundub. The village also had a bakery that also served Dueimat, Wad Killian and parts of Banat al Hamda. The village school served all the above mentioned villages and additionally Al Figaiga. The village lay elevated a few metres on an old sand dune, and one third of the village was on the northeastern side, open to sand invasion, while the two remaining thirds of the village were within the prosopis buffer zone.

The Tundub village analyses followed as much as possible the same approach as has above been described for Al Figaiga, Dueimat, Al Hosh and Wad Killian. The fuelwood consumption of the Tundub bakery was assessed directly with the bakery employees.

### 4.4.3. Externalities and other impacts in relation to sand invasion on homesteads

**Basis for calculation.** The property markets for housing and housing estates in January 2004 were not well developed in the Gandato scheme and not even in Shendi town itself. Almost all houses in the framed research area of the Gandato Scheme were first built as two-room or single-room houses, which were then surrounded by a 500 $m^2$ walled yard. In January 2004, a two-room house had a standardized price of 200,000 SD (100,000 SD per room), with a homestead yard wall that cost 50,000 – 100,000 SD surrounding it. As this wall can surround several household units (i.e. that of the original couple’s house and those occupied by younger generation households) and the style of the yard wall could be different, the wall was omitted from the financial analysis. Some households invaded by sand on a continuous basis did not have the money or energy to rebuild their houses properly every or every second year, and, in the poorer unprotected parts of Wad Killian, a one-room house had therefore a value of only 20,000 SD. In Al Figaiga, Dueimat, parts of Tundub, and parts of Banat al Hamda (a separate part of Al Hosh village) houses had, apart from the two brick rooms, also verandas on at least two sides of the house that had the roof extended over them and were supported by brick or wooden pillars at the corners and a brick or wooden low wall along the edges of a concrete floor. According to the villagers, such houses were worth 250,000 – 300,000 SD, but not too many of these houses had by January 2004 been sold on the free market. Stated market prices appeared anyhow to be insensitive to the location in the villages.

The houses in the main parts of Al Hosh, parts of Banat al Hamda, Tundub, and those of the 30 households of Wad Killian village were not protected by prosopis shelterbelts and had mostly only the standard two rooms with tight wooden or metal window shutters and wooden doors, but no verandas. Some younger couples lived inside the walled yard of the older couple and had only one-room houses attached as a third room to the original house and thus shared part of the original household facilities. During the data collection in July 2003, January 2004 and June 2004 it became evident that the reason for a simpler house construction without verandas in the above mentioned villages was the dust and sand particles flying around in the village every day, which did not allow for sitting outside or sleeping on a veranda. Therefore it could be determined that the lack of verandas was an externality of the combined effect of sand invasion and no shelterbelts protecting the village from flying dust and sand.

Another part of the impacts of sand invasion on homesteads stemmed from weathering of the houses caused by sand particles hitting the walls during windy days, as well as from the actual weight of sand against the outside walls. Large amounts of sand could also penetrate into the houses and fill parts of them. Many households at the sand invasion frontline had therefore to rebuild their houses annually or every second year. The cost of rebuilding was calculated on an annual basis for such households using information from the household interview answers. Some households in Al Hosh had begun to save on rebuilding expenses by using as part of the house a wooden hut that could be moved within the houseyard away from the invading sand. Field observations in Al Hosh in combination with information from villagers confirmed that houses that had been abandoned some eleven years ago were at the time of the household survey completely levelled to the ground by the sand and the wind, while some five-year-old ruins were standing less than a metre above the sand.

In the context of sand invasion, sand particles with a diameter from 0.05 to 2.00 mm are classified as sand, while smaller particles are classified as dust. Sand particles transported by wind accumulate as dunes of various shapes and sizes. The wind can cause three different types of movement of sand: (a) suspension, (b) saltation, and (c) surface creep (sheet sand). Suspension means a vertical uplift of sand by strong turbulent winds that occur more seldom but carry sometimes the dust thousands of kilometres (Mattsson and Nihlén 1996). Saltation is a bounding process, where sand particles are lifted between a few centimetres and some metres up into the air by a side wind. The surface creep means that larger particles are initially rolled over the surface, but may sometimes become lifted some centimetres at a time by gusty winds. About 95 percent of the sand movement is through saltation. For dune sand the impact velocity has been found to be approximately 4.4 m/s at one metre height above the ground. The threshold velocity for sand movement has been found to be 4.7, 5.8, and 8.9 m/s for dunes, coarse sand wash (up to 3 mm grains), and desert pavement surfaces, respectively. Transportation of sand by wind at 13.9 m/s for one hour would equal the amount of sand transported at 8.3 m/s for 14.3 hours or that of 5.5 m/s transported for 611 hours (FAO 1985; Bristow 1996).

Many villagers in the vicinity of the sand invasion frontline in Al Hosh were not in practice able to excavate sand as much as they actually would have preferred to, due to several reasons. For many, the first reason was the lack of cash for paying 2,000 SD per hour for either a tractor or ox-based excavation of sand. An ox was of use for sand excavation inside the narrow yards where tractors could not operate. In Hassania, for the 70 unprotected homesteads of Al Hosh and the 30 unprotected homesteads of Wad Killian there was also another major reason. These homesteads were in the first frontline of the sand invasion from the north-east and were therefore spread out over a large area some 20 to 100 metres apart, and, in many cases, without any yard walls at all. Here, the distance between houses acted as privacy protection instead of the yard walls, which would only have trapped large amounts of the invading sheet sand that now could freely pass by. An optional form of the Hassania houses had a small and narrow yard between two houses with walls up to the roof level (about 2.5 - 3 m high), and thereby the yards did not trap so much sand. The 30 Wad Killian households at the sand invasion frontline were very poor and had only poorly built houses of mud and residue materials that cost some 20,000 SD each.

For the other households in the unprotected sand edge parts of Al Hosh, sand excavation was not a real option, as there was no place to put the excavated sand; the sand would only blow into the neighbours' yards and the agricultural fields directly behind the village. Yet many households excavated sand for over 20 hours per year within their house yards and put it out into the streets. In the first street that ran parallel with the sand edge in Al Hosh there was a layer of sand approximately 1.5 – 2 m thick, blown into the village, which made this street completely unusable. The house compounds on both sides of the street were not in much better condition either, and many of the houses had been abandoned. Many people were unable both to rebuild their houses and to move away as moving away cost more than staying on. Their best option could be to take over an abandoned house from a former neighbour who had left the village for good.

**Methods of valuation.** By using the house designs of Al Figaiga and Duheimat with a veranda as the standard for a prosopis shelterbelt-protected house, the annual externality of living in a less valuable house could be calculated for each household by using as base data the collected household interview information. The house value for each individual household interviewed in Al Figaiga and Dueimat ranged from 150,000 – 300,000 SD, depending on the basic construction of the house. In the unprotected villages the houses of the respective households interviewed were thus valuated against the corresponding shelterbelt-protected houses of Al Figaiga and Dueimat. The deviation in house value became thus the annual externality from living in a less valuable house. This method of valuation can thus be described as *an avoidance of cost approach* (cf. Kahn 1998; Hanley and Spash 1998; Dixon and Pagiola 1998; Boxall and Beckley 2002).

The calculated estimations were based on household and group interviews, own field observations and the January 2004 Landsat satellite image. This information also gave an indication on how many households could currently possibly be affected. The plain Landsat image was too coarse for actual spotting of the individual houses, but the complementary GPS points taken gave the length of the village sides against the sand invasion, which was then divided by 27 m, which equals the square root of a 500 $m^2$ houseyard with some additional allowance for streets between houseblocks. As Al Hosh is a large village with 850 households living in six sub-villages of 50 – 250 households each, each sub-village was separately analyzed based on interviews, field observations and the Landsat image wherever possible. Wad Killian also contained small separate village parts which were handled in similar fashion.

The collected information from each sub-village indicated how the sand invasion had proceeded in them during the preceding 11 – 12 years. The annual need for house rebuilding at the sub-village level could thus be somehow triangulated. One could estimate that houses that had to be rebuilt every or every second year had two sides and the roof as well as the yard wall (in case that existed) against the wind, needing more often rebuilding. For the calculations this was estimated to equal some 60% of the building price of a new house, and for houses inside the main Al Hosh some 40% rebuilding of a house would be necessary. The valuation approach used followed the *replacement cost or avoidance of cost approach* (Kengen 1997; Bishop 1999).

In the same way information was also collected on the number of households that had moved within the village and therefore needed to build a new house on a new compound site. These moving households had first to pay 2,600 SD for the new building site and then additionally 200,000 SD for the construction of a new two-room house. The valuation thus followed the *financial market price* *and replacement cost approach*, although the market price did not really fluctuate freely (Kengen 1997; Bishop 1999).

The household survey and group interviews also assisted in determination of an estimate for the number of households that had left during the previous two years. This estimate was then divided by two to get an approximation for the financial year June 2002 to June 2003. Based on the interview results, tables were constructed separating the sand invasion impacts for each sub-village in Al Hosh and Wad Killian during the preceding 12 years.

The estimation of the actual annual need for sand excavation followed again the same basic pattern of using information from the household survey. It was estimated that, on average, two lorry loads of sand would have to be deposited elsewhere. This estimation is coarsely based on the average amounts of sand excavation hours stated by the households interviewed and then extrapolated to also cover the non-interviewed households. As no deposition site was known to exist, the calculation had to be based on how much two lorry loads would cost transported to some mountain valley about one hour's drive from the village. Such a mountain valley could probably be sealed later by concrete or similar material. A part of the sand loads could perhaps also be deposited within the prosopis buffer zone, where the prosopis roots would eventually stabilize the sand in similar fashion as for the sand earlier deposited in the area. The valuation method used in this case is called the *replacement cost* or *avoidance of cost method* (Kengen 1997; Bishop 1999).

Without the prosopis shelterbelts and buffer zone the same sand invasion problems as the current ones in Al Hosh, parts of Tundub and part of Wad Killian would be prevalent in all the framed area villages. This was actually the case for some time in the 1980s and early 1990s before prosopis was officially introduced to the area, so this would be a real and not just a hypothetical consideration. The financial analysis in this scenario was based on the household survey information containing also earlier experiences of the population, own observations from the data collection in the field in the area and in adjacent sand-invaded villages, and the GPS-improved satellite images from various years to estimate the numbers of households which would be affected by sand invasion. In Scenario B thus *the same valuation approach was used, but the magnitude of impacts affecting households was estimated for a scenario without shelterbelts*. The Scenario C case was estimated as a situation where no sand invasion was occuring.

To better understand the resettlement process and the consequences of resettling, ten full household interviews were conducted in Khartoum (four interviews), in Shendi (two interviews), and in Al Abdutab and Taragma (two interviews in each village) as presented in Annex B. The aim with the targeted interviews was to identify what externalities follow a resettlement process caused by sand invasion in a village, to present some impacts, and, further, to link these to the household surveys conducted in the framed area in the Gandato Scheme. The consequences of an even worse sand invasion than the one encountered in the Gandato Scheme could be observed in practice in Al Abdutab and in other villages on the western side of the Nile. The observations and some targeted household interviews made it easier to assess the sand invasion impacts also for the Gandato Scheme, and this also supported the satellite image interpretation work.

#### 4.4.4. Impacts in relation to improvement in microclimate for agriculture

**Basis of calculation.** The fields in the Gandato Irrigation Scheme were far from ideal for research on crop yield improvements achieved with shelterbelt protection using prosopis. Therefore it is relevant to first present some background information on the climatic and crop cultivation settings in the area.

The climate in Shendi is hot almost throughout the year, except for December and January during a short winter season. The annual mean temperature is 28°C, and the monthly mean maximum temperature from April to June is in the range of 40 - 42°C. During December and January the minimum temperatures can reach below 10°C. For the rest of the year, the monthly mean temperature is between 21 - 26°C. The scanty and erratic rainfall is normally about 100 mm per year and occurs mainly during the period from July to early September. The relative humidity (as measured at dawn) varies from 30 - 40% between January and February, from 20 - 27% between March and June, and then increases to 30 - 45% between July and December. The solar radiation is very high all year round, and this in combination with the high temperature causes a water deficit in the area. The crop production therefore has to rely on irrigation or on rainwater harvesting in valleys to succeed. The north-easterly winds are strongest from April to June, after which the winds turn around in late June or early July and come from the south-west during most of the rest of the year (Bristow 1996; Haider et al. 2004).

Farmers in River Nile State were usually well aware of the need to rotate between crops in each field, so as to be to able achieve nutrient replenishment at the site (cf. Bagayoko et al. 2000). The irrigation farming has three main seasons, which are: (a) the Shitwi (winter) season from November to March during which horsebeans, haricot beans, onions, wheat, lablab, alfalfa, vegetables, spices and various fruits are grown; (b) the Seifi (summer) season from May to August during which summer vegetables and alfalfa are grown in the scheme, and sorghum, okra, and fodder maize are grown outside the schemes in distant valleys and on river islands; and (c) the Damira (flood) season from August to November during which fodder maize, groundnut, sorghum, alfalfa and lablab are grown in the schemes (ElRahman 1991; Doka et al. 2003; ElHassan 2004;). The farmers use mostly the same crop varieties year after year. The irrigation frequency, water amount and N fertilization all affect various crops differently, which means that external disturbances have an effect on the harvestable yields (Saeed and ElNadi 1998; Hussaini and Amans 2000; Ibrahim et al. 2002).

In general terms, the tenant farmers have basically two major farm-operating objectives, which are profit maximization on market-oriented farms and household sustenance on subsistence-oriented farms. Under uncertainty farmers will face a set of profit probabilities corresponding to each of the available decision options, and for each case they will decide whether they will take a lower certain profit or a higher but more uncertain profit. Most farmers therefore act in the middle between profit-maximizing and sustenance (McConnell and Dillon 1997).

In River Nile State there have been both scientific experiments and practical applications with shelterbelts for improving the crop growth and yields. The Agricultural Research Corporation also conducted some of its studies there in 1999 and 2000 on the fodder yield of sorghum in alley cropping trials with the tree *Acacia stenophylla*. This tree species is an introduced Australian thornless acacia which has a growth pattern somewhat similar to prosopis. The trial in question was established at the Hudieba Agricultural Research Station some 80 km north of Shendi along the Nile in an area that has climatic and soil conditions almost identical with those in the Gandato Irrigation Scheme.

At the time of the alley cropping trial the *A. stenophylla* trees were growing in two hedgerows of 90 m length. There were a total of 30 three-year-old trees with an average height of 4.3 m and a spacing of 3 m in the row and six metres between the rows. The alley cropping trial had only two treatments, which were the alley cropping and the control, each replicated three times. The trial was fertilized with urea, irrigated on a weekly basis and hand-weeded once in two weeks after crop germination. Meteorological measurements were conducted with instruments installed around and inside the trial area for the whole duration of the trial (Haider et al. 2004).

According to Haider et al. (2004), the relative air humidity rose in the alley cropping treatment during the whole trial period and was, on average, 50%, which was 11% higher than in the control without trees. The maximum temperatures in the alley between trees (over all months) were reduced by 1.5 $^{o}$C, while the minimum temperatures increased by 2$^{o}$C. The highest reduction in temperature occurred during the hot August and September months. With alley cropping, the average daily wind speed was reduced by 31%. In July, during the first month of crop growth, the wind speed was reduced by 37%. This compares well with results from another scientific shelterbelt trial in the Kerma Basin in Northern State, where trees reduced the wind speed by 30 – 40% (Musnad and ElFadl, 1984). In the alley cropping trial at Hudieba the overall solar radiation reduction in the alley was about 42% as compared to the control conditions. Alley cropping saved 25% of the irrigation water, while the soil moisture content of the control without trees was 54%, 55%, 73% and 92% of that of the alley at 15, 30, 45, and 60 cm soil depth respectively. Further, the yields of sorghum (fresh weight), in alley cropping ranged from 273% to 300% of the yields obtained without trees (Haider et al. 2004).

ElRahman (1991) conducted, in the Zeidab Irrigation Scheme, an assessment of the annual cotton yields from three field blocks cultivated in 1968/69, 1970/71 and 1971/72 without shelterbelts of prosopis and from 1973/74 to 1976/77 with such protection. In the 1960s and the 1970s the cotton fields were centrally operated by the scheme management and not by individual farmers themselves as has been the case during the last decades. The study concluded that the shelterbelts for these three large field blocks increased the cotton yields, on average, by 69% to 117%, depending on the specific field block and year. The largest yield increase was found in a field block that had shelterbelts perpendicularly against the northeasterly wind. Also Mutsambiwa et al. (1998) assessed in another trial that farmers of the Community Forestry Project in Ed Debba (Ergy) in Northern State could due to shelterbelts prolong their irrigation interval for crops to ten days, instead of the five days which was the practice before the establishment of shelterbelts with prosopis.

Bayoumi (1976) and Pereira (1989) concluded that semi-permeable wind shields such as shelterbelts with trees which can reduce the wind speed by about a half are optimal for crop protection and to be preferred over non-permeable wind shields. A semi-permeable shelterbelt reduces the straight side wind on the leeward side, since it causes less downward turbulence directly behind the shelterbelt. On the other hand, a non-permeable wind shield turns the wind straight upward and over the shield in strong turbulence that strikes directly downward behind it. The height of the shelterbelt is another important factor in the shelterbelt structure. A semi-permeable shelterbelt can reduce the wind speed by about 20% over an area that measures 15 - 20 times the height of the shelterbelt. Tree species selected for a shelterbelt should have an optimal combination of fast growth, a long life cycle, high tolerance to environmental hazards and preferably a high economic value. Shelterbelts perpendicular to the main wind direction have the optimal protective effect on crops (Bayoumi, 1976; FAO, 1985; Mohamed et al. 1995).

Shelterbelt effects on crop yields vary from year to year due to variations in annual weather conditions. In wet years the shelterbelt protection effects may be levelled out in comparison to open fields, while in dry years the shelterbelt effects are significantly higher (Qi et al. 2001). However, in conditions like those in the arid and semi-arid Sahel there will always be a necessity for shelterbelts for obtaining good crop yields. The most important impacts of shelterbelts on crop cultivation are related to wind speed reduction, subsequent increases in the relative air humidity and temperature changes. Depending on how densely trees are planted in agroforestry systems there may further be profound differences in the solar radiation reaching the ground. In the tropics there is normally a too high solar radiation level for many crops, especially for those that originate from subtropical or temperate ecozones, and these would grow better with some protection from full sunshine (Haider et al. 2004).

**Method of valuation.** As earlier mentioned, the Gandato Irrigation Scheme constitutes a case where there are difficulties in clearly distinguishing and separating the various shelterbelt effects. Household surveys and satellite images available from earlier decades indicated that there had been sand invasions affecting the Scheme for some time - also in areas which are currently protected by prosopis shelterbelts. Field observations during the present work also confirmed that the current shelterbelts had largely stopped the sand from reaching the fields,

Soils in the Al Figaiga fields next to the bordering shelterbelt were analyzed from soil samples (soil analysis results are presented in sub-chapter 5.3.9.). Modifications in the Scheme layout due to the natural changes in the course of the Nile and failures of the scheme management in keeping sufficient irrigation water available during the whole cropping season were also likely to cause variation in crop yields. The Al Figaiga and Dueimat fields were not only protected by a shelterbelt next to the fields but there was also a buffer zone of prosopis in a belt varying from 900 to 3,500 m in width from Banat al Hamda up to the railway line next to Wad Killian. The large Al Hosh village lay between the fields and the open bare area from where the sand invasion came and acted as a kind of shelter with openings between the sub-villages. In these openings there was no protection, and, in fact, some sand was blown into the fields even along the streets through Al Hosh village.

The Gandato Scheme lies today in the arid ecozone, but to an extent the Nile mitigates the climate in a belt of about two kilometres on either side of the river. Even in the fertile riverine zone the agricultural production is mainly achieved with irrigation. Without irrigation it would be possible to cultivate only some sorghum and okra, while all other agricultural crops would fail. Under such conditions all protection that can be provided for crops would impact beneficially on the yield levels. A shelterbelt can not only improve the conditions for crops to grow in a harsh climate but also be the crucial factor that allows growing of new crop types and offers thus new economic opportunities in the area. With sufficient shelterbelt protection and water for irrigation, the riverine area in Shendi has a relatively good potential for agriculture. However, if the current riverine micro-climate is destroyed by sand invasion or even worse, by sand dune invasion, the cultivation potential will be almost totally lost.

For calculating the externality effects of shelterbelts on the agricultural fields in the framed research area of the Gandato Scheme the household survey results were used in combination with the January 2004 Landsat satellite image. Furthermore, the Gandato Scheme management provided statistics for the four previous cropping seasons on crop species and on areas cultivated for each crop, in the Al Figaiga and the Dueimat fields combined, and for the Al Hosh fields separately. At the time of scheme establishment there had been five feddans of land available for each of the tenant farmer households participating in the Gandato Scheme. In all, there had in 1986 been 250 feddans for 50 households in Al Figaiga, 150 feddans for 30 households in Dueimat and 500 feddans for 100 households in Al Hosh. The shelterbelt-protected fields of Al Figaiga and Dueimat constituted a combined 80% of the total field area for Al Hosh. In the calculations the field area of protected villages was therefore scaled up to correspond to the unprotected fields of the Al Hosh area.

During the four years (1999 – 2002) for which the Gandato Scheme data were available the scheme management had not been able to provide sufficient and reliable irrigation water, and most of the tenant farmers had therefore established their own irrigation systems by building wells or own water pumps into the Nile. Only three of a total of eleven interviewed tenant households in Al Hosh and four of a total of 21 tenant households interviewed in Al Figaiga and Dueimat actually relied on the Scheme's centralized irrigation system. Centrally irrigated fields were excluded from the analysis in cases where the irrigation had been insufficient. The fields used for analysis thus mainly consisted of those which received the tenant farmers' own reliable irrigation water. The analysis used a feddan (0.42 ha) as the operational crop cultivation unit. The valuation approach used here can be referred to as a *productivity based valuation approach* (Kengen 1997; Hanley and Spash 1998; Dixon and Pagiola 1998 ; Bishop 1999).

For Scenario B, the Al Figaiga and Dueimat crop yield results from Scenario A were recalculated without the shelterbelt effect, by scaling down the Al Hosh results to 80%, while the Al Hosh results where kept as in Scenario A. Thereby the total Scenario B economic estimate became 1.8 times the economic loss of Al Hosh fields in Scenario A.

#### 4.4.5. Income losses due to sand invasion-induced social visits

**Basis of calculation.** In the interview sessions it became clear that during the preceding 12 years numerous households had left from various parts of Al Hosh and social visits had become an economic burden both for the households remaining in the village and for the urbanized relatives who had resettled mainly in Khartoum or Shendi. However, no households of the Hassania sub-village of Al Hosh had left the village, although it was located at the very front line of sand invasion. These households belonged to the ethnic Hassanian population group, which had only recently abandoned its pastoralist lifestyle and did not yet have kinship ties to cities. Neither had any households resettled from any of the four other villages that were studied in the Gandato Scheme.

Many social visits between the villagers of Al Hosh and resettled households in Khartoum and Shendi were necessitated by family events such as weddings, birthdays, various commemorations and funerals. Quite many of these events at least partly involved working days, which meant that household heads in the villages had to leave their work for at least one day to travel to Khartoum or Shendi for the event. The household surveys clarified that the income generation was not in all households affected by these social visits. It was mainly the wage labourers, skilled craftsmen, teachers, merchants and other business people, who annually lost some income-earning days on this kind of travelling. In contrast, farming work could often be postponed for a day or two without difficulty or be carried out by neighbours, if necessary. For others than the farmers it was mainly the male household head or an adult son who brought in the cash income for the household.

**Method of valuation.** The household survey of Al Hosh was examined, and the households with labour, skilled labour, merchant or other business income were singled out. The relevant part of the respective annual income in each of the selected households was divided by 360 (days) to obtain the daily income during the year. Thereafter it was checked from the respective household interview how many trips the household head had been making to Khartoum or Shendi in the previous year due to social events; these days were counted and multiplied by the daily income estimate. The respective combined lost income was summed up and a joint average income loss was calculated for all the relevant sample households from Al Hosh. Then the percentage share of households with such social visit expenses was calculated from the total number of households interviewed in Al Hosh. The resulting percentage share was then multiplied with the total Al Hosh household number (however, Hassania was exempted from calculations) to cover for the whole Al Hosh village. The valuation approach can be seen as *a loss-of-earnings approach* (Kengen 1997; Hanley and Spash 1998; Dixon and Pagiola 1998; Bishop 1999; Ward and Beal 2000).

The respective actual travel expenses (at market price) for sand-invasion-induced social visits were calculated already in the household survey and occurred for Scenario A only in the case of Al Hosh. These household travel costs were summed up and divided by the number of households interviewed to get a mean annual household travel cost for the whole village (Hassania exempted). This figure was then multiplied with the total number of households in the whole Al Hosh (Hassania exempted) to get the community social visit costs. The valuation of travel expenses for all households was based *on market prices for social visits.*

For Scenarios B and C the same approaches were used for labour and business income losses after it had been determined from satellite images, household interviews and field observations (triangulation) how many of the households would be potentially affected in each village in these two scenarios. For Al Figaiga, Dueimat, Tundub and Wad Killian, the average annual cash income was also calculated and weighted to give the percentage shares of the Al Hosh average annual cash income losses in Scenario A. The weighted annual average cash income for the other villages was then used in the Scenario B and C calculations.

### 4.4.6. Impacts of prosopis on health and mobility

**Basis of calculation.** The household surveys presented in sub-chapters 4.3. and 5.2. indicated that in the Shendi area prosopis did not have major direct negative impacts on human health through thorn injuries, as these did not require much medical treatment there. In fact, the household surveys identified some potential indirect benefits of prosopis for human health. Such benefits were related to cleaner air due to lower particle content, which also meant fewer respiratory ailment problems. A physician in Al Hosh stated that about 5% of the villagers suffered from respiratory ailments, and some of the household and group interviews also pinpointed the existence of these problems. Another benefit was identified in Wad Killian and two other villages, Al Abdutab and Taragma, located a few kilometres north of Shendi. These three villages had before the early 1990s been under heavy sand invasion pressure that had caused an economic burden on livelihoods, but due to the establishment of prosopis shelterbelts the villages had been able to recover economically. Several household heads stated that they had started to sleep well after the shelterbelts with prosopis became effective against sand invasion. People from the unprotected parts of Al Hosh and Wad Killian confirmed further that they could not sleep well during windy nights, as they were afraid that sand would heavily invade their house and homestead and they could not afford the expenses from that damage.

Other problems stated were that during heavy rains the completely bare and compacted sand plain outside Al Hosh, Tundub and Wad Killian became flooded due to water runoff from higher ground. The sand had piled in the border zone between the plain and higher ground and could not easily be removed. This loose sand made transportation difficult at some sites.

**Method of valuation.** The above externalities were complex and could not easily be monetised separately. The local medical staff may have been not even willing or able to reveal the whole health situation. It seems obvious that a well-functioning prosopis shelterbelt between the villages and the frontline of sand invasion would reduce the externalities related to sand invasion to a much lower level. In this case one could see positive externalities in a shelterbelt of prosopis. Thus the costs associated with the establishment of such a shelterbelt, from Wad Killian in the south via Tundub to the Al Hosh main village in the north, could be seen as a modest estimation of the values of the health-related risks and stresses in the area (cf. Figure 4 in Annex C which illustrates how new shelterbelts could be established).

The Forests National Corporation (FNC) office in Shendi, the FNC nursery manager in Soba and the villagers themselves provided cost estimations. The expenses of this shadow project also used relevant plantation establishment and management information as described by those who had established shelterbelts in practice in arid and semi-arid areas in Sudan (cf. Luukkanen and Saarainen 1985; Hallikainen 1985; FAO 1985; Branney and Connelly 1990b; Bristow 1996; Mohamed et al. 1997; and Mutsambiwa et al. 1998). The shelterbelt establishment expenses were distributed over 25 years, giving for one year only 1/25 of the total expenses in the financial analysis. In reality, such expenses would occur mainly during the first two years of the shelterbelt establishment phase and all expenses would have to be calculated in net present value (NPV) figures. As the NPV year was seen as the fiscal year under study, there was no real need to include a discount rate in the shelterbelt establishment expenses. This valuation method represents the *shadow project approach* (Kengen 1997; Dixon and Pagiola 1998; Bishop 1999).

The above-presented shadow project approach has its flaws as there are also some other beneficial impacts hidden in the shadow project value and these thus overlap with other valuation exercises of this TEV. However, as explained above, the health and mobility impacts would need more elaborated research efforts to be satisfactorily monetized and separated from these other benefits. It could also be foreseen that an economic one-year estimate derived from the shadow project as calculated above only provided a modest value for the health and mobility impacts as compared to what they are in reality (in terms of medicines, reduced incidence of diseases, lower income generation due to stress-related insomnia, life expectancy reduction as well as mobility problems), particularly for the approximately three hundred most actutely affected households.

In Scenario B the health risks and the stress linked to sand invasion would increase in the absence of prosopis. For the expanded externalities, the costs of a new shelterbelt for Wad Killian, parts of Tundub, Duheimat and Al Figaiga were added in the same way as described above, similarly to the shelterbelts calculated and described for Scenario A. The same flaws in the shadow project approach as were presented for Scenario A are repeated also in this scenario, with also the same explanation why the approach should be used. Further, it can be stated that the above-mentioned parts of the framed study area (i.e. these for Wad Killian, Tundub, Dueimat and Al Figaiga) were in Scenario A already covered by patchy prosopis stands in the whole bufferzone between these villages. It can therefore be anticipated that prosopis would easily repeat its current establishment process in most parts the bufferzone also in a Scenario B case (when starting completely new shelterbelt establishment). A condition for this was, however, that the shelterbelts were properly tended during the first two critical years and watered as necessary.

### 4.4.7. Impacts in relation to livestock rearing

**Basis of calculation.** To better understand the value of prosopis as forage in the Gandato framed area in the financial year 2002/2003, it was necessary to know the livestock situation for the years before the presidential decree on prosopis eradication in Sudan had been issued. The household livestock herd sizes for 1989 could be somehow estimated from the data provided by ElRahman (1991). Official provincial livestock statistics information was also available for the years 2000 – 2002; from it the overall current trends in livestock rearing in the province could be derived for the study period.

The household interviews conducted in the present study formed the basis for determining the livestock situation in the framed area villages in 2003, and they also gave an approximation for the situation a decade earlier, which could be compared with ElRahman’s (1991) findings on the livestock owned by households in the Shendi area in 1989. For the externality study it was even more useful to know the number of animal feeding units separated into goats, sheep, cattle and donkeys, as this determined the amount of fodder needed per household. In the case of goats and sheep, young animals were estimated to account for a third of an adult annual feed unit each, while for cattle and donkeys the annual offspring accounted for half an annual feed unit each.

For the Scenario B case prosopis had to be hypothetically excluded (as a desk study exercise) from the research area and the respective forage removed from the calculations. It can be assumed that also the other free-grazing opportunities would be substantially reduced as a consequence of this hypothetical prosopis eradication. An increased impact of factors, such as no shelter for seeds and young plants against sand invasion, hotter and dryer climate conditions, too intensive solar radiation, more concentrated over-grazing, heavier water run-off, and more compacted soils, would prevail in such a situation. On the other hand, there would be a few places where grasses and other indigenous plants would grow better, without competion with prosopis.

A study from the north-western desert region in India conducted by Singh et al. (2003) indicated that the coverage percentage of grass and small woody perennials on drifting sand dunes was only 1 – 17% of the coverage under neighbouring protective trees. The shelterbelt experiment conducted by Haider et al. (2004) in River Nile State and presented above in sub-chapter 4.4.4. indicated that sorghum grew better in the vicinity of trees than in bare open areas. The sorghum yield of that particular experiment was about three-fold inside the alley cropping area as compared to the situation outside it. The growth conditions for indigenous grasses and herbs in Gandato may not have been as harsh as in the Indian case, nor as good as in the controlled alley cropping trial described above. A rough estimate for the indigenous vegetation coverage for open areas was therefore derived for the framed research area. It was estimated that only 25% of the indigenous free-grazing forage available in Scenario A would be available in Scenario B when prosopis was absent in the area. This equals only 6.25% of the total free-grazing forage available in Scenario A when prosopis is also present. This rough estimate provides the magnitude of a proxy monetized without jeopardizing the financial analysis.

**Methods of valuation.** In the household economic studies it was of interest to know how much of the total costs for fodder the individual households accrued during the financial year 2002 - 03. From a public goods perspective it was necessary to focus on the amount of milk and meat provided in a Scenario A situation for all households in a village and to compare this with the Scenario B situation in which no prosopis was available in the area. The approach was to see how much more fodder costs there would be at the individual household level to keep up the Scenario A amount of livestock production in the households also in a situation corresponding to Scenario B. In Scenario A, prosopis and the natural vegetation forage together form a large part of the total fodder and subsidize the livestock rearing to a major extent, as the forage expenses are not financially internalized into the household economies. To internalize and monetize these expenses one first needs to determine the respective percentual shares of the fodder produced in the scheme and the free-grazing forage from prosopis and other indigenous vegetation. The cash and subsistence income from milk and meat sales for each respective household provided an overall economic monetized value for the respective household’s fodder. This monetized value was then divided further into monetized fodder and forage shares. The *valuation method used for Scenario A can be seen as substitute of goods approach* (Kengen 1997; Bishop 1999).

After all the prosopis and 75% of the other, indigenous free-grazing forage in the bufferzone had been excluded from the financial analysis for Scenario B, there was still some free-grazing forage remaining from the field surroundings, remote valleys and commercial fodder. If one would in a the Scenario B case still try to produce the same amount of meat and milk as obtained in Scenario A, the annual commercial fodder costs would increase substantially. It can thus be assumed that the annual quantities of meat and milk produced in 2003 were close to optimal for the households, with an exception for the poorest ones, which would never really face an optimal situation. The transition from free-grazing forage into increased cash expenses for fodder was reflected as a loss in the public good support of meat and milk in the households due to a lack of free-grazing prosopis forage. The *valuation method used for Scenario B can be seen as substitute of goods approach followed by the mitigation of cost approach* (Kengen 1997; Bishop 1999).

Another calculation was also conducted to estimate the total number of affordable animal feeding units that would be left in a Scenario B situation in case the individual households would actually pay for the fodder. This indicated what would in reality happen in the villages without free-grazing forage opportunities. These calculations were made for each of the framed area villages separately.

### 4.4.8. Conservation of the native woody vegetation and impacts from utilization of prosopis

**Basis of calculation.** Almost one third of the land area between latitudes $10^o$ – $18^o$ N in Sudan is affected by desertification which ranges from slight to severe. Desertification is the main environmental threat in northern Sudan. The natural woody vegetation is there sparse or almost absent and confined to the riverine zones of the Nile, the Atbara and the seasonal watercourses. There has been a continous pressure on the valuable forest resources which prosopis has been able to reduce at several localities during the last decades. The demand for fuelwood and browsing from trees is constantly high in the dry northern region. The climatic extremes that occur in this region, such as long drought periods, flooding of the Nile, and high windspeeds, are further contributing to the pressure on natural resources. Seeds and seedlings of indigenous tree species suffer from sand invasion, drought and browsing, as well as from trampling by livestock. There are also agricultural activities such as new irrigation canals, road construction and similar infrastructure that have disrupted the water availability for the natural vegetation with die-outs as a consequence (Bashir 2001).

According to ElRahman (1991), Bristow (1996), ElHassan (2004) and the FNC offices in Shendi and Matemma[4] the cutting of indigenous trees is restricted in the area outside the riverine zone, as these trees belong to the state. Any person who sells more than ten bundles of fuelwood or some few poles will have to pay a tax. The FNC in Khartoum prepares annually a price list for wood products and the respective taxes. As neither the official selling prices nor the tax rates in 2003 were in relation to the local market prices in the Shendi area - the official prices were much higher than the local market prices - this seemed to act as an unintentional but strong constraint on selling large amounts of wood. Only dead trees from the riverine zone and pruned branches of large trees in the villages and in Shendi were sold in larger quantities, for instance, to the brick-making industries. The locally unadjusted and inflexible prices and corresponding tax levels on wood materials appeared to contribute to the protection of the indigenous woody vegetation outside the riverine zone.

Almost all the fuelwood used by the households in the Gandato scheme area was prosopis wood from the prosopis buffer zone which the households either collected themselves or bought locally. Also the poles used were mostly cut in the prosopis bufferzone, and a small part was also purchased in the villages by traders who visited the villages. Both commodities could be defined as collected locally in the framed area. Charcoal was sold in River Nile State, but it was usually produced in Gedaref and Kassala States (for instance in the Rahad and the New Halfa Irrigation Schemes), from

[4] Personal communication in 2004.

where new truck loads often arrived to meet the demand. The charcoal in Gandato was in the financial year 2002 – 2003 mostly made from prosopis, but there also existed some *Acacia seyal* charcoal that cost 200 SD more per sack and was mostly used in Shendi town. A sack of prosopis charcoal cost 1,200 SD in 2004.

From old Landsat satellite images from 1972 and 1987 it could be seen that the present-day prosopis bufferzone was almost devoid of any woody vegetation in those years. Even a currently dense *Capparis decidua* stand of some 1600 $m^2$ in area and about 5 – 6 m tall could not be seen in the satellite image from 1987. Therefore the prosopis growing in this bufferzone was not competing with any native woody vegetation but rather filling an empty ecological niche. The previous indigenous vegetation cover had been destroyed some decades earlier due to overuse of the fuelwood resources and grazing around villages. Prosopis in the bufferzone and the shelterbelts had, despite the annual 2.2% human population growth rate and an increasing livestock population in the province, been able to grow and expand annually in the area. The reason for this was obviously the substantially faster growth rate of prosopis in comparison with indigenous acacias and other tree species. Prosopis was therefore able to provide annually the villages in the framed research area with much more fuelwood and poles per hectare than any native tree species could do and thereby saved the indigenous vegetation over a larger area in River Nile State. This beneficial externality had therefore to be taken into account in the financial analysis.

Alternative methods for assessing the beneficial externality of prosopis for environmental conservation were explored. The best option was to find in Sudan or elsewhere in the Sahel region a suitable tree species trial where native acacias and prosopis would have been scientifically compared on arid or semi-arid rainfed land. The approach was to determine the growth rates of prospis and relevant native woody species and to calculate a fast-growth multiplier for prosopis. No long-term species trials conducted under managed conditions could be found in Sudan. The Community Forestry Project in Ed Debba had tried 18 native and introduced species in Northern State, and *P. juliflora* was reported to have by far outperformed all other species (Mutsambiwa et al. 1998). However, no information was provided on the experimental design or the trial duration.

The Northern Region Irrigation Rehabilitation Project (Branney and Connelly 1990 a,b) in the Kabushiya Irrigation Scheme near Shendi has reported that *P. juliflora* is the best shelterbelt species for the area and that after one to two years of initial irrigation during the establishment of shelterbelts the tree was able to produce annually, on a three-year rotation, 11.9 tonnes/ha of fresh weight wood, equivalent to 7.1 tonnes/ha/year of dry wood. A five-year rotation would also yield 7.1 tonnes /ha/year if larger wood material was required for construction poles. Each hectare would supply 31 persons with fuelwood. The demand for fuelwood per household had since then started to decrease; in the financial year 2002 – 2003 many households increasingly also used charcoal, liquid gas or even electricity and, therefore, prosopis stands could fulfill the fuelwood demand for even more persons per hectare.

From outside Sudan some relevant information was available from trials carried out at the Bura and Hola forestry research stations at the Tana river, in Kenya, reported by Johansson et al. (1993), Kaarakka et al. (1993), Otsamo (1993), Otsamo et al. (1993), Johansson (1995) and Kaarakka (1996). The species trials reported from Bura and Hola were on both irrigated and rainfed land. The prosopis landraces used in the trials were either of the so-called Bura variety of *Prosopis juliflora*, first planted in Hola in the1970s or a *P. juliflora* variety imported from the Tendelti region in Sudan in the mid-1980s. Of the tree species the trials in Kenya included various acacias such as *A. tortilis, A. senegal, A. mellifera* (both of the latter species imported from Tendelti and Gedaref in Sudan), *A. nilotica, A. zanzibarica and A. horrida*. Of these species only *A. tortilis, A. nilotica* and *A. mellifera* grow in River Nile State in Sudan in the framed research area. *A. zanzibarica* is similar to *A. seyal* and, like that species, also grows on clay soils. *A. horrida* and *A. ehrenbergiana* (the latter growing in River Nile State) have also growth and stem form similarities.

In Kenya the growth rates of the two prosopis varieties outperformed those of all the above-mentioned acacia species both when irrigated and rainfed. On rainfed land the mean annual increment (MAI) of prosopis usually ranged from 1.7 to 4.7 $m^3$/ha (avering 2.0 $m^3$/ha), while the acacias had MAIs from 0.1 – 2.0 $m^3$/ha (averages about 0.3 $m^3$/ha). A 53-month-old irrigated species trial in Hola included prosopis that had an MAI of 16.6 $m^3$/ha while the acacia species in the same trial had a MAI of only 0.1 – 0.4 $m^3$/ha. The trial had not got any irrigation during the last 42 months before the inventory, which makes the growth performance of prosopis even more remarkable. The reference sources (Johansson, 1995; Johansson et al. 1993) do not inform whether prosopis roots had reached the ground water level before the irrigation had ceased, which could be an explanation for the great difference in growth performance between prosopis and the acacias. In another species trial in Bura, Kenya, reported by the same authors as mentioned above, *A. senegal* and *A. mellifera* reached a net MAI (or an MAI also accounting for the survival rate) of 2.9 and 3.0 $m^3$/ha, respectively, while the two prosopis varieties had net MAI values of 17.9 and 18.7 $m^3$/ha, respectively. In most of these trials prosopis showed a 3.8 to 6.5 times faster growth rate than the acacias.

Prosopis stands can also be managed by pruning and singling out the stems. ElFadl (1997, 2003) studied in the Tendelti region in Sudan the effect of removing of all lower branches up to one half or up to three quarters of the total tree height. Both treatments resulted in significantly faster growth than pruning up to only one quarter of the total tree height or no pruning at all. The annual rainfall in this trial was about 100 mm or about the same as in the Shendi area. Following the pruning, the annual diameter increments recorded were 1.3 and 2.3 cm during the first and second year, respectively. The trees in the control group had during this time only 0.3 and 0.9 cm of annual diameter increment, respectively. More frequent pruning increased the biomass volume increment even further. The same author also studied the volume development after thinning of coppice shoots growing from the same stump. He found that trees thinned to three stems per stump had a larger basal area per individual tree than trees thinned to either one or five stems per stump, but the total vertical tree height was not affected. After a removal of side branches, prosopis concentrates its growth to the main bole and therefore the bole diameter increases rapidly. In this way, it was possible to increase the MAI for useable wood in prosopis from 0.3 to 2.3 $m^3$/ha.

Ojala et al. (1993) also thinned coppice shoots of prosopis in Bura, Kenya, and found that reducing the stems of *P. juliflora* to six, four, and two stems per stump, respectively, affected the stem thickness but had no significant effect on the total wood volume produced. Felker et al. (1990) have reported that prosopis trees heavily compete with each other and there is a substantial self-thinning process that leads to optimal growth and stems evenly distributed with a total number of about 100 stems per hectare.

Regarding coppice stands, ElFadl (1997) concluded, that prosopis has a good ability to resprout. A stump height of 30 cm gives the highest biomass yield in the new generation, although the same number of coppice shoots, as compared to stumps cut at 10 or 50 cm. Shiferaw et al. (2004) concluded from their study in Ethiopia that a 50 cm stump coppiced better than a 30 cm stump.

As far as the charcoal consumption is considered there are different options for the incorporation of beneficial public good effects. The charcoal in the study area in Sudan is almost all produced from prosopis wood, which makes it a beneficial impact of prosopis in the framed area. To determine whether the beneficial public good should be a multiplier of the current charcoal amount sold in the framed area one has to know whether prosopis is to be eradicated also in the rest of Sudan or only in the framed area. As the tree is difficult to eradicate (Otsamo 1993; Johansson 1995; Pasiecznik et al. 2001) it would appear likely that there will also in the future be prosopis available for charcoal production from at least some places in Sudan. Prosopis needs to be controlled in many places in Sudan by cutting, and thus its wood sold on the market will in any case save areas of native woody vegetation from being excessively harvested.

**Methods of valuation.** By synthesizing the above information provided by various researchers, a growth rate performance in prosopis amounting to five times that of the local native acacias could be assumed. This multiplier of five for fuelwood and poles from prosopis could even be considered a modest estimate that did not take into account the better resprouting ability or response to pruning found in prosopis as compared to those in native acacias. However, prosopis growing in the buffer zone of the framed area in the Gandato Scheme was probably not evenly pruned in the whole bufferzone, which means that full effects of pruning and thinning could not be assumed.

The use of prosopis charcoal also supports the environmental conservation of the local indigenous vegetation around the Grandato Scheme. In this analysis the prosopis charcoal multiplier became +1 instead of +5 for the case of local fuelwood. The reason for this was that this wood energy source was beneficial to the framed area communities, although the charcoal came from semi-arid lands from which the native acacias had to a large extent been cut away before the appearance of prosopis. The monetized value for wood products of prosopis is a public good value, while as a value for conserving the local environment it is a beneficial externality. The final monetized value for Scenario A was *derived through a market price for fuelwood, poles and charcoal* (Kengen 1997; Dixon and Pagiola 1998; Bishop 1999).

In Scenario B there would be no prosopis stands in the framed research area, which means almost automatically that the fuelwood, poles and charcoal would have to be purchased elsewhere. The public good support to the communities and to River Nile State will become different depending on whether there exists prosopis or a similar introduced tree resource elsewhere that could substitute for the non-existing local resources. In case such an introduced tree species, acting as a substitute, did not exist, it probably means directly a heavy toll on the native acacia vegetation somewhere else in in River Nile State. For the financial analyses, it was assumed that there would exist prosopis somewhere else in the state to substitute for the local wood resources. If that was not the case it would mean that all the use of fuelwood (for households and bakeries), poles and charcoal would be devastating for the natural acacia stands; and this would increase the externality multiplier to five for the combined fuelwood, poles and charcoal consumption. The selected more modest calculation option seemed anyhow to suffice for this study. The monetized value in Scenario B for conserving the local environment is a beneficial externality value. The monetized value was *derived through a market price for fuelwood, poles and charcoal with a further addition of the mitigation cost approach, which also then captured some intrinsic values* (Kengen 1997; Dixon and Pagiola 1998; Bishop 1999).

*Bakery utilization of prosopis wood.* The framed research area in Gandato Scheme also had some bakeries that used prosopis wood which needed to be included in the TEV calculations. No other commercial activity was dependent on fuelwood. Brick-making kilns were, for instance, situated closer to Shendi and used other wood. There were three bakeries in the framed research area, located in Al Figaiga, Tundub and Al Hosh, which used fuelwood from the surrounding prosopis bufferzone, with some small additions from other sources, such as dead wood from the villages. Furthermore, small amounts of prosopis fuelwood were also sold from the framed research area to the Shendi bakeries. Information on the monthly amounts of fuelwood consumption was requested from the respective bakeries, and this information formed the basis for the derivation of the annual wood consumption. This prosopis fuelwood amount was also multiplied by five to incorporate the beneficial public good support of local prosopis fuelwood. The *valuation exercise was conducted similarly to that for household fuelwood* as described above.

*Fencing.* The January 2004 Landsat satellite image was detailed enough to allow the length of the prosopis shelterbelts bordering the fields of the Gandato Scheme to be distinguished for the Al Figaiga and Dueimat villages. These were the only prosopis fences bordering the scheme fields, and most other prosopis inside the scheme could be counted as weeds (some farmers also produced prosopis timber stems). There also existed some separate dry fences with prosopis branches, for instance, at a field in Al Figaiga and some smaller ones for either keeping the livestock fenced in, or keeping the livestock fenced out from the storage places for onions (“rakuba” in Arabic) which are types of huts built of prosopis poles with thatch roofing made from palm leaf or other similar materials but with no walls.

The use of cut thorny prosopis branches for fencing was for the farmers a substitute for an installed barbed wire fence. The establishment of 110 m of a two-metre-high fence of barbed wire cost 100,000 SD in 2003 in the New Halfa Irrigation Scheme in Kassala State. Shendi had similar economic conditions as the New Halfa Scheme, and therefore the price of a similar barbed wire fence could be considered as the same. It was estimated that a barbed wire fence could last for 25 years and a prosopis fence possibly for five years with new branches being added on the top when needed; a one-year benefit from a prosopis fence could thus be calculated. The valuation was based on the *substitute of goods approach* (Kengen 1997; Bishop 1999).

*Sheds and shade for livestock.* Sheds built using a corner of the house yard and some brick pillars and a low wall of mud or wood planks in the front would cost around 2,500 SD for five goats or sheep, while two cows would require a shed costing around 4,000 SD. These could also be used for shade for livestock. From the household interviews the number of animal feeding units could be calculated for all the framed area villages. By standardizing the sheds for each type of animal units as described above the total amount of goat/sheep and cow sheds, respectively, could be estimated for each village. As prosopis was already providing this kind of environmental service in the form of taller trees under which the livestock could seek shade in the surroundings of Al Figaiga, Dueimat, Tundub and the main parts of Wad Killian, the number of sheds needed could be calculated as a beneficial externality in these villages, while the Al Hosh households had to use sheds specifically built for their livestock, which was then an additional cost for the village. The valuation was based on the *substitute of goods approach* (Kengen 1997; Bishop 1999).

For an estimation of the needs for prosopis sheds for livestock in Scenario B, specifically constructed sheds were used as a substitute for those made from prosopis for the whole framed area, instead of just for Al Hosh as in Scenario A.

### 4.4.9. Impact of prosopis on the income generation and the education level of children

The household economies of petty shop owners were grouped into those in sand-invaded areas and those with a house and shop in the shelterbelt or in otherwise protected surroundings. The annual income levels of both groups were then compared. For some other occupations such as donkey cart drivers and labourers it was not useful to distinguish any groups of people separately in the protected and in the sand-invaded areas, as these worked in different places around the villages and thus it was more difficult to spot shortfalls in their income generation in a one-year time slice. This would have required more in-depth knowledge of income development from several consecutive years.

The most vulnerable people living in the unprotected part of Wad Killian or along the sand edge of Al Hosh had a pastoralist ethnic background (Hassania, Ababda or ZuAdab) and had during the last few decades settled on a permanent basis in the villages and taken up any work that was available for them. Their level of education was, even without counting the effect of sand invasion, low. Teachers in village schools had a right to determine different school fees for children on the basis of the respective household's income. This made an impact analysis of a household's educational losses due to sand invasion difficult in a one-year time slice. The *effect of prosopis on the above two impacts was therefore merely described*. The same approaches were also applied in Scenario B, but here expanded to cover also those villages that in Scenario A were protected by prosopis.

### 4.4.10. Impacts of prosopis in relation to land rehabilitation

**Basis of calculation.** The fact that prosopis is not particularly suitable for planting inside an agricultural irrigation scheme has been known already for some decades (Otsamo 1993; Johansson 1995; Mutsambiwa et al. 1998; Pasiecznik et al. 2001). The prosopis found in the Gandato Scheme area mainly consisted of shelterbelts and a bufferzone covering the southeastern part of the framed research area in a 900 to 3,500 m wide belt between the irrigation scheme and the area up to the railway line on the eastern bank of the Nile.

On the western bank of the Nile, opposite to the Gandato Scheme, there was another irrigation scheme with a narrower prosopis bufferzone. Its fertile vegetation zone consisted of only a hundred metre to one kilometre wide area adjacent to the Nile. In fact, satellite images and field observations indicated that heavy sand invasion had occurred in that area and prosopis and *Leucaena leucocephala* had been introduced in some locations to protect the land from further sand invasion. The prosopis bufferzone at the Gandato framed site comprised the actual village areas, their extensions, as well as the area for fuelwood collection and livestock free-grazing. It had shelterbelts on the inside against the southern parts of the fields, and Wad Killian village had a 600-m long shelterbelt along the railway line towards the bare land. Also Banat al Hamda (a separate part of Al Hosh) had some shelterbelts which had had to struggle for survival and did not much protect the village.

The fact that prosopis impacted directly on soil rehabilitation in the bufferzone was of fairly low interest for the local population, as the area was utilized only for the above-mentioned purposes. The externality values of livestock grazing and wood collection have already been valuated under other headings in the present study, and double counting will therefore be avoided. What remains to be calculated mainly consists of the positive soil rehabilitation environmental services which appeared comparatively small and difficult to capture from a monetized externality point of view. These may have built up option values that were not much utilized in 2003, although these services were beneficial for the whole buffer zone. Some of these environmental services were already described in Chapter 2.2. while some site-specific services are further described in 5.3.9.

Environmental services encountered were elaborated using both results from previous studies and soil analyses conducted within this study. The soil improvement and land rehabilitation services in the Gandato Scheme potentially included the following issues:

- Increase in soil organic matter;
- Increase in soil moisture;
- Sequesteration of carbon in vegetation and soil;

- Reduction of water run-off;
- Biological nitrogen fixation;
- Improved soil porosity;
- Sand dune and soil stabilization;
- Ground water protection and purification of soil near and inside the villages;
- Reduction of nutrient leakage;
- Protection of the riverine zone and its biodiversity;
- Mitigation of the resource utilization pressure (e.g. as related to grazing and fuelwood consumption) in the riverine area;
- Protection of the village infrastructure; and
- Biodiversity improvement (comprising the below-ground biodiversity, the flora and the fauna) in comparison to the compacted denuded land in the bufferzone.

### 4.4.11. Impact of prosopis on scenic values in the area

The villagers were during the household surveys invited to state whether prosopis was in their opinion good or bad, which was recorded on a scale from "very good" to "very bad"; coded from 1 to 5, respectively. The villagers were further requested to state whether prosopis was in their opinion beautiful or ugly, coded as 1 and 2 respectively. The answers were then *statistically analysed on a normative scale and described without further monetizing*. The reason for the selection of this particular approach will be better understood as the results are presented in sub-chapter 5.3.10.

No new valuation method for the calculation of Scenario B was introduced, but the argumentation on what would happen without prosopis is described based on the household surveys, field observation and satellite images.

### 4.4.12. Impacts of prosopis on biodiversity

As already presented in sub-chapter 2.5.2. and also commented in sub-chapter 3.3., an economic valuation of the local biodiversity values in the area would be likely to be come up with a monetized value that is not credible. It is far better to merely just describe it and conclude that prosopis provides a certain positive impact on the biodiversity of the framed area. The overall TEV analysis needs just to determine that the Benefit/Cost Ratio for prosopis is net positive despite the fact that all benefits have not even been monetized. Therefore the current biodiversity situation at the study site was only assessed based on reference literature and some support from own field observations of birds and other wildlife in the framed research area and its surroundings. The FNC in Shendi had a forest and ornamental tree nursery in Al Glea village about half-way between Shendi and the framed research site along the Nile. Jointly with the head of the FNC office in Shendi, a tree species inventory was conducted in the riverine zone close to the nursery, and all woody species – indigenous and introduced - were identified and listed by their scientific names.

### 4.4.13. Protection of potential historical and archeological sites in the area

The same approach as used for biodiversity was also applied for historical assets in the framed area. Known historical sites in the neighbourhood of Shendi were registered from reference literature in combination with the household survey findings and own observations in the framed research area. The results were left at a descriptive level, as the full extent of the pre-historic and historic remains of the area may not be properly known even to archaeologists.

### 4.4.14. Main detrimental impacts of prosopis in the framed area

All relevant detrimental impacts of prosopis were identified and quantified during the IEE and EIA/SIA work comprising the household survey results presented in subchapters 4.3 and in 5.2. From them, an average household weeding cost was calculated over all households interviewed in Al Figaiga, Dueimat and Al Hosh, disregarding whether a household had tenancies in the scheme or not. In this way it was easier to reach a cost value for each village, although only a sample of households from each village had been interviewed.

It should be noted that the own weeding costs in households were left out from the analysis in the same way as those for own labour in crop cultivation, livestock rearing, or wood collection activities. For wealthier households the weeding activities were conducted mostly by hired labour and thus they were eventually mostly included in the TEV analysis. For the weeding activities of the poorer households', however, there was no opportunity income available. This issue is therefore of fairly neglible character.

The main irrigation canal in the scheme could be distinguished from the Landsat satellite image from January 2004, and it was also shown in the hand-drawn map of the Gandato Scheme from 1986 prepared before the canal network reconstructions. Through walking around in the Scheme area it was possible to see which parts of the main canal were invaded by prosopis. It should be noted that prosopis was not the only woody species that had invaded the main canal. A few other native and alien tree and shrub species were also spreading in the riverine area. The extent of canal weeding mainly due to prosopis could be estimated from field observations and the January 2004 satellite image. The Zeidab Irrigation Scheme, some 80 km north of Shendi, had just completed the weeding of its main canal and the expense calculations from Zeidab were provided by the Forests National Corporation staff in River Nile State for use in the present study. The valuation method used was thus the *financial market price approach.*

During the household and group surveys the villagers were also asked on how many cart, car, minibus, truck or tractor tyre punctures caused by prosopis thorns there were per time unit in each of the villages. The villagers were further asked about the availability of tyre repair workshops and the cost of repairing punctures. If the villagers repaired the punctures themselves, as happened in some cases, then the prices given by a village repair workshop were used. Persons who did the repair work themselves were usually professional tractor or car drivers who got a monthly or weekly salary, whereby the repair work did not affect their personal income, although these persons lost some time from their main work. However, it is not ascertained how busy these drivers were during a week and thereby it is not known how constraintful the repairing of the punctures really was. The valuation was based on the quantification of punctures in the area, and this was then monetized using *financial market prices* from the village or Shendi town repair workshops.

With prosopis absent from the area in Scenario B, there would be no negative impacts from prosopis in the villages. For Scenario C, the results from Scenario A could be cross-used between villages; this supported the estimation of the frequencies, magnitude and expenses for tyre puncture damages. It was obvious that in Al Hosh there would be more punctures with more prosopis around.

# 5. RESULTS

## 5.1. Welfare situation in the New Halfa Irrigation Scheme

### 5.1.1. Structure of household economies and socio-economic settings

The New Halfa Irrigation Scheme and its societal settings have already been described in sub-chapter 4.2. Below are the household economy results for the four population groups (tenants, western and eastern Sudanese landless, as well as nomads) presented one at a time. The set-up in the framed area of the New Halfa Irrigation Scheme is complex and requires in-depth understanding of many issues, which are explained below. The situation in the framed area is summarized in Figure 6 and in Tables 13, 14, 15, 16, 17 and 18 in Annex C.

The size of the statistical sample of interviewed households from the framed area of the New Halfa Scheme was 5%, which equalled 110 households interviewed out of the overall 2,210 households living in the area. The interviewed households could be further divided into population groups as follows:

- Tenant farmers: 2.4% or 30 out of 1240 households;
- Western Sudanese landless: 5.1% or 30 out of 585 households;
- Eastern Sudanese landless: 8.7% or 30 out of 345 households;
- Nomads: 50% or 20 out of approximately 40 households that were at the time of the interview living in vicinity of the area.

**Structure of household economy of tenant farmers in the New Halfa Scheme.** The framed research area of the present study in the New Halfa Scheme comprised five brick house villages for tenant farmers and the respective schemelands and freehold lands belonging to these villages at the southern end of the scheme in Faras and parts of the Hagir sub-section of the Debeira section. The villages in the area had been built with Egyptian funding as compensation to the Nubian tenant population for their resettlement from the Wadi Halfa area due to the construction of the Assuan dam and its reservoir on the Sudanese side of the international border.

Table 1 in Annex C shows the household economy of the tenant farmers by cash income quintiles. All except nine households earned their main income from agricultural activities. One of the nine exceptional household heads interviewed had abandoned farming completely and did labour work for others, and another household head worked as labour foreman in the scheme, while the seven other households received their main income from skilled labour work, remittances, and transportation business while also farming. The majority of the tenant farmers received a cash remittance sent to them from their relatives in Khartoum, Kassala, Port Sudan or Saudi Arabia, which constituted in the poorest cash income quintile a third of the total average annual cash income. Without this remittance several of the poorer tenants would have had a negative annual cash income. The impact of prosopis on the tenant farmers' household economy will be presented under separate heading below. Most tenant farmers were not particularly hard-working and could have earned more through a more intensive own labour effort. A typical tenant household had a few milking animals (cows, goats or sheep) with their offspring, and each household was thus at least partly self-sufficient for milk. Some few households produced milk beyond their own needs and traded in it.

**Socio-economic background of the tenant farmers.** Table 2 in Annex C shows the socio-economic background of the 30 tenant household heads interviewed in villages 1, 3, 4, 7, and 33 respectively (six household heads interviewed from each village). The total number of tenant households in the five villages was approximately 1,240. The New Halfa highway and the main canal run close to each other through the framed research area, and village 3 was located close to the road on the eastern side, while villages 1 and 33 lay about 1.2 km from the road on the west and east side, respectively. The remaining villages 4 and 7 were both situated some 4 km from the highway to the east along dirt roads which for the first time got a layer of gravel on them in 2003. There had been a shortage of water in the scheme, and many tenants were facing irrigation problems. This had led to low agricultural economic efficiency and a massive invasion of prosopis in the area.

There appeared to be a slight positive connection between the distance from the highway and the main irrigation canal on the one hand and the household agriculture gross margin income level for the cash income quintiles 1 to 4 on the other. In the poorest income quintile, 50% of the households were from the remoter villages, while quintile 2 comprised middle-distance villagers, and cash income quintile 3 households at all distances from the highway. Cash income quintile 4 comprised almost exclusively households from villages at medium distance from the highway and the main canal. Cash income quintile 5 mainly consisted of households that earned a large part of their cash income from various businesses. Here households from remote villages had a high incidence of being in this income quintile, and the probable reason for this was that agriculture was not profitable; this had forced these households to seek better income sources. Quintile 5 household heads were also younger and had more education than many other household heads. Noteworthy was also that the richer quintile households had more family members living in the village, which probably was related to the fact that in the poorer households many family members had left the scheme due to insufficient income opportunities.

**Direct impact of prosopis on tenant household economy.** Table 3 in Annex C shows the direct impact of prosopis on the tenant household economies as seen from a gross margin income generation point of view. The tenants had substantial cash expenses and cash outlays from prosopis. The tenants allowed the western or eastern Sudanese landless people to rent or share scheme land or freehold land that had been invaded by prosopis. Part of the deal was that the landless person cleared and weeded the field from prosopis before cultivation and, while cultivating, continued to weed prosopis until the crop harvest. Most of the charcoal and poles used by tenant households were also bought, and this meant that the tenant farmers only saw cash outlays and expenses in relation to prosopis, although they had a sizable annual subsistence income from free-grazing forage of which the major part consisted of prosopis.

Table 13 synthesizes the share of prosopis and other environmental income out of the absolute total income of the tenant households. The average forest environmental share of the absolute total income was 14% if the free-grazing forage was economically internalized into household economies and 24% if it was not internalized. The income share of prosopis in Table 13 includes its benefits and cash outlays for fuelwood, poles and charcoal, as well as its costs from weeding and sharing agreements between the tenants and the landless households.

Prosopis also had other impacts on the tenant household economies, which became evident later on in the research process and necessitated a further closer study on the individual household economies. The survey included 30 tenant households of which ten cultivated their whole allocated 15-feddan scheme land by themselves. Of the remaining households, 16 were sharing or renting part of their scheme land with an another household (usually a landless family). The remaining four households either did not cultivate their scheme land at all or had all of it rented out. The overall average household gross margin from crop cultivation on scheme land was approximately 483,000 ± 82,000 SD for those households which cultivated all the 15 feddans by themselves. Only three of the ten households that cultivated all their scheme land by themselves with paid labourers as support had another major income source, such as crop cultivation on freehold land or transportation business, which could have provided a higher gross margin income than the scheme land cultivation. Three other households interviewed had substantial cash remittances from relatives, which enabled a more relaxed lifestyle.

The 16 households which shared a part of their scheme land had an annual average gross margin from this land of 141,000 ± 57,600 SD, which meant that the sharing-cultivating households earned, on average, approximately 342,000 SD less annually than their non-sharing neighbours. Reasons for the income reduction were many and needed therefore to be studied more carefully at the individual household level to distinguish the main ones. Only a few of the tenant farmers shared or rented out more than 5 feddans out of the total 15 feddans they possessed. They always kept the cotton cultivation land for themselves, while they shared or rented out either the groundnut or the sorghum fields or both. The unit profitability for cotton fields was by far the highest; the groundnut profitability was at the medium level, while the sorghum profitability was the lowest one. The tenants' income loss from just sharing of 5 feddans would have meant in cash at the 2003 price level some 6,000 SD for sorghum and some 70,000 SD for groundnut after operational costs had been subtracted. On top of the reduced profits when sharing and renting out part of the scheme land, most tenants also paid up to 25,000 SD (normally 10,000 – 15,000 SD) for a western Sudanese landless household to weed a hawasha (5 feddans) invaded by prosopis. Usually this was part of the sharing or renting contract between a tenant farmer and a landless person.

A substantial part of the income losses from crop cultivation in parts of the Debeira section stemmed from prosopis root systems causing a major obstacle for ploughing operations in the fields. A much heavier and stronger tractor had to be used in these fields, which increased the costs of ploughing. The ploughing expenses increased from a mere 6,000 SD to 30,000 SD per five feddans due to the heavier machinery needed. This was particularly the case in villages 4 and 7, which were further away from the main canal and had the above-mentioned lower cultivation income.

A further reason for the income reduction was that 12 out of the 16 households that shared/rented out some scheme land also had some other income activities, which considerably consumed their total daily working time. Such other activities where cultivation of own freehold lands, businesses, teacher work and selling of milk. These activities could often be more profitable than the cultivation of the scheme land, particularly in those parts of the scheme that lacked irrigation water. Of the remaining four households, two were also receiving cash remittances from relatives living in a city in Sudan or abroad.

Apart from the weeding fees included in the sharing contracts, tenant farmers also employed labourers to assist them in the cultivation of their non-shared fields, and this labour work also included prosopis weeding, which corresponded to an average 10,133 SD per tenant household, which equals totally some 12.56 million SD for the whole framed area.

There was in the financial year 2002/2003 a substantial lack of water, which was accentuated in the remoter parts of the scheme. The Khasm al Ghirba dam was filled with silt, and the water that had been stored inside the scheme canal network had caused a substantial increase in the vegetation growth in the canals as well as in prosopis on the banks and inside the canals. Several tenants and landless persons operating farmlands further away from the main canal stated in the household interviews that their fields did not receive enough irrigation water. The scheme section management stated that the normal amount of water per irrigation time for a block of 300 feddans was 90,000 $m^3$ diverted from larger canals. In parts of the Debeira section this was insufficent, as the canal vegetation also consumed water, and thus 22% more water was needed to achieve the normal irrigation level on these fields. The irrigation cost 1,800 SD per irrigation time for 5 feddans of land. The tenants paid annually 60,000 dinars (4,000 SD/feddan for the 15 feddans of scheme land), which included the land rent and some irrigation. Additional irrigation on scheme land or freehold land was paid on top of the standard fee.

Based on the above calculations, it can be estimated that in some cases almost half of the average income reduction of 342,000 SD could be accounted on prosopis through an increase in ploughing costs, weeding expenses, sharing-contract weeding payments, and obstruction of water flow in the feeder canals. The rest of the income reduction would then be due, for instance, to substituting the income generation from the scheme land by other activities, other reasons for lack of water, or an overall reduction of crop yields in the scheme. When stating this estimate for the impact of prosopis on the tenants' crop cultivation income, one also has to bear in mind that it has simultaneously diverted some of the tenants into other businesses and livelihood activities, which provided these households with an opportunity to earn more money than was the case for those that focused their whole income generation on scheme land cultivation. Nevertheless it is understandable that the tenants were not too fond of prosopis in the scheme area.

**Structure of household economy of western Sudanese landless in the New Halfa Scheme.** Most of the western Sudanese landless household heads stated during the individual interviews that their occupation was farmer, but as seen from Table 4 in Annex C, a majority of the 30 household heads interviewed was earning more cash income from prosopis cutting and labour work than from the actual crop cultivation. Crop cultivation had perhaps a greater cash turn-over during the year, but the gross margin income after the deduction of operational expenses was not so high.

Among the income quintiles 3, 4, and 5 there were households which obtained a large share of their annual income from selling of milk and meat. Some full-time drivers and camel and donkey transporters were also able to earn an income which placed them in income quintile 5. The two wealthiest households earned their cash income from businesses, and their cash income could well be compared with that of the wealthiest tenants, although the quality of living conditions was not the same. The western Sudanese landless households had to work much harder as compared to the Nubian tenant farmers to earn the same amount of money. A typical household had a few milking animals (cows, goats or sheep) and their offspring, and it was at least partly self-sufficient in milk. A few households were able to sell milk, and for some of them this was a major cash income source.

The average western Sudanese landless agriculture income was about 62,000 SD (the mean of 20 households' crop cultivation gross margin income). This figure should then be expanded by the weeding contract, clearing, wood selling and charcoal opportunities that the invading prosopis accumulated for those who shared, or rented, such fields.

**Socio-economic background of the western Sudanese landless population.** The western Sudanese landless group of people mainly comprised immigrants from western, south-western, and central Sudan as shown in Table 5 in Annex C. The 30 interviews conducted covered households with ethnic backgrounds such as Bargu, Tama, Fur, Niseria, Lahawi, Salami, Zagawa, Gimir, Risegat, Masalit, and Dagawi, which all are traditional farming population groups. There were approximately 585 western Sudanese landless households in the framed research area. A few Hadandawas from Kassala State had also settled with these long-distance immigrants and made their livelihoods as petty shop owners or in similar occupations.

Most of the western and south-western Sudanese immigrants had arrived in New Halfa already between the 1960s and 1980s when there was severe drought in their home regions. In the 1990s the immigrants mainly came from the central Sudan states, and many of these immigrants still have the main part of their families living elsewhere, while the adult males earn money and aim at, for instance, purchasing of a piece of irrigated farmland back home in White Nile or Gezira States. These latest arrivers were hard-working men, and among them an opinion prevailed that they could earn more in the New Halfa Scheme than back home. They carried out the labourious prosopis cutting or were involved in intensive freehold land cultivation, and they were almost all to be found in the two highest income quintiles, which together with the settled businessmen constituted the wealthier households in this population group.

The poorest households among the western Sudanese landless population were found in the outskirt camps of the scheme, but the wealthier households lived closer to the highway. In the camps close to the highway the differences between the western and the eastern Sudanese landless populations were smaller, and the camps had to some extent become more mixed than before. The poorest households had no education, while the education varied between no education at all and completed secondary education among the more affluent households.

**Direct impact of prosopis on western Sudanese landless household economy.** Table 6 in Annex C shows the direct impact of prosopis on the income generation of the western Sudanese landless households. The households of this population group were utilizers of prosopis more than any other population group in New Halfa. With the exception of income quintile 3, all households had their main cash income source from prosopis. Four of six households interviewed in income quintile 3 earned their largest part of cash income from milk sales, which explains their low household cash income from prosopis and high subsistence income from free-grazing prosopis forage. With the exception of a few households which purchased charcoal, all the rest of the households earned both cash and subsistence net income from the utilization of prosopis. Some households were specialized in prosopis cutting and charcoal making, which provided them a stable monthly cash income and placed them in the two highest income quintiles.

A prosopis invasion in the scheme provided these landless people a better opportunity to share or rent farm land in the scheme. In case prosopis would not have added substantial amounts of work to the tenants' crop production, the tenants would not have shared or rented out their scheme land and freehold land as often as they did. Prosopis acted in 2002- 2003 therefore as an income and societal status equalizer between the population groups as seen from a distance. Those landless households that shared or rented agricultural fields were, in the same way as the tenant farmers, constrained by the additional expenses caused by prosopis on crop cultivation. Often these landless farmers even had to cushion the reduction effect of the income of the tenant farmers, because such sharing agreements were usually arranged with the tenants being the stronger party.

Table 13 summarizes the share of prosopis and other environmental income out of the absolute total income of the western Sudanese landless households. For the poorest landless households almost all income is related to the forest environmental income and this income share is then steadily regressive towards the wealthiest households. If the forage is internalized into the household economies, the share of cash income ranges from an average of 42% among the poorest households to an average of 79% among the wealthiest ones. Prosopis constituted about half of the absolute total income for a median western Sudanese landless household.

**Structure of household economy of the eastern Sudanese landless in the New Halfa Scheme.** Table 7 in Annex C shows the structure of the income generation of the eastern Sudanese landless household economies. Poorer and middle income quintile households earned their income as labour in farming and other tasks for others in the scheme, as well as from prosopis cutting and weeding, but seldom from charcoal making. Some of the middle income households were further able to share with a tenant household some farmland in the scheme. Relatively wealthy households interviewed in this group were those representing the Shukria, the households with substantial milk production from the outskirts of the Scheme, and one Majasid teacher's household. For these households prosopis was a voluntary cash outlay, since the benefits could have been consumed by these people free of charge by collecting the wood by themselves. None of the eastern Sudanese landless households earned much cash income when compared to the tenant farmers or the corresponding western Sudanese landless households.

**Socio-economic background of the eastern Sudanese landless population.** Table 8 in Annex C shows the socio-economic background of the eastern Sudanese landless who comprised the original pastoralists and scattered village population that had lived on the Butana plains west of the Atbara River in Kassala State already before the New Halfa Irrigation Scheme was established in 1964. The ethnic backgrounds of these people were Hadandawa, Ben Amir, Shukria, and Majasid (Gaalian). There were about 345 eastern Sudanese landless households in the framed area and additionally, the Shukria people who live some four kilometres outside the framed area and one kilometre outside the scheme. The number of the Shukria households living outside the scheme could not be checked from any reliable source, but the Shukria themselves stated that there were about 500 households belonging to this ethnic group in this part of the scheme surroundings.

With the exception of the Majasids from the area between the scheme and Ed Damer town in Nile Province at the confluence of the Nile and the Atbara Rivers, the eastern Sudanese landless appeared to have a lower overall society status than did the landless people from the western and central parts of Sudan. Two probable reasons for this lower status were perhaps, firstly, their pastoralist background in a scheme where crop cultivation was the first priority and, secondly, their low educational level. Many of the eastern Sudanese landless stated themselves that they felt like outsiders in the scheme. Most of the households that lived in the framed area belonged to three camps close to the highway that run through the middle of the scheme, but some 130 households also lived next to tenant villages 4 and 7 far from the highway. Outside the framed area there was also the large Shukria village, which was partly included in the analysis, as the villagers were connected through work opportunities with the framed area. The Shukria were also allowed to divert some irrigation water to parts of their sorghum fields just outside the scheme. Most of their sorghum fields were, however, cultivated as rainfed agriculture. They even employed paid labour to do the weeding when needed. Some Hadandawa households in the camp outside tenant village 7 were cattle herders and grazed their cattle both inside and outside the scheme; they were able to sell substantial amounts of milk and meat, which was their major source of cash income.

**Direct impact of prosopis on the household economy of the eastern Sudanese landless people.** Table 9 in Annex C shows the direct impact of prosopis on the household economy of the eastern Sudanese landless population. Households interviewed collected by themselves all their fuelwood and part of their poles from prosopis stands. Group interviews identified that some eastern Sudanese landless people also made charcoal, although no such household was actually directly interviewed. Those households which did not produce charcoal by themselves often bought some for their domestic use. The households interviewed seldom bought commercial fodder and, therefore, their livestock had to utilize mainly prosopis and other free-grazing forage as fodder. Similarly to the western Sudanese landless group, also this population group had gained opportunities to share farmland after the invasion of prosopis had begun in the scheme. In contrast to the people who cultivated crops inside the scheme, the Shukria had been successful in weeding all prosopis from their fields.

Table 13 synthesizes the share of prosopis and other environmental income out of the absolute total income of the eastern Sudanese landless households. This population group received almost all of its income as subsistence income, and the prosopis-related income accounted, on average, for 55% of all the income. The cash income was mainly used for the payment of household operational expenses.

**Structure of household economy of the nomads in the New Halfa Scheme.** Table 10 in Annex C shows the structure of the household economies of the nomadic population. The poorest households among the nomads had almost no income (only some irregular petty labour earnings in the scheme) but were supported by other households they migrated with or by a son or daugther working in a town. Almost all of these households grew some rainfed sorghum on the Kassala plains in the rainy season. The poorer households could manage on 100 – 150 SD a day for purchased food items. The main activities that provided a cash income for the households in the income quintiles 2 - 5 were camel transportation, livestock sale, and, for two households, some shared cultivation in the scheme. A substantial income source for about half of the 20 households interviewed was cash remittances from other households or from relatives working in Sudanese cities or in Saudi Arabia. The wealthiest Rashaida household received all its cash from the household head who was a shop owner in Saudi Arabia from where he sent money on monthly basis.

**Socio-economic background of the nomad population.** Table 11 in Annex C shows the structure of the household economy of the nomadic and semi-nomadic population. The nomads mainly belonged to the various branches of the Rashaida, who originally had immigrated from Saudi Arabia some 150 years ago. These people were of Middle Eastern or even Indian origin with colourful clothing. Some 40 nomad households were living within a few kilometres from the framed area. The total number of nomad households in the scheme area was probably less than one hundred.

The nomads were still to some extent outsiders in the scheme area, and while interviewing them one had to be wary of not being insensitive to cultural issues. This difficult interviewing situation caused inaccuracy in the data for financial analysis concerning five households which later had to be discarded from the total of 23 household interviews with the Rashaida. The Rashaida stayed each year from late November until late June inside the New Halfa Scheme, after which they returned to the Kassala plains when the rainy season started, for preparing their rainfed sorghum fields. Most of the Rashaida interviewed stayed in the scheme outside the framed area, but they migrated along the highway in both directions and sometimes allowed their livestock to graze in this area. The grazing almost exclusively consisted of prosopis forage, but sometimes the nomads rented a field for a month after the harvest to allow their livestock to feed on the stubble and grass, and sometimes they also fed some sorghum grain to their animals. The Rashaida moved around and lived in groups of five to ten families which could change in composition each year. There were also extended households, and the largest such household had 25 members consisting of three adult sons with their respective families that had stayed together with their father's household after the father's death. The Rashaida could still have large herds of sheep and goats and a few camels. In 2002-2003 some households also had cattle that provided milk income.

In the dry season, there were also some semi-nomadic herders in the scheme who belonged to the Bewadra ethnic group that had settled some 20 km outside the framed area. The young males of these families grazed their 25–30-head cattle herds in the framed area. The cattle produced substantial amounts of milk, which was sold every day to Kassala along the highway for a higher price (70 SD/ litre) than what was earned by the rest of the scheme population (i.e. 30 – 50 SD/litre). Two Bewadra herders were interviewed on their respective household economies, and their information was included in the financial analysis. Thereby a total of 20 households were included in this particular financial analysis.

**Direct impact of prosopis on nomad household economy.** Table 12 in Annex C shows the direct impact of prosopis on the nomad household economies. Prosopis almost appeared to be the direct reason for the nomads migrating to the New Halfa Scheme area during the dry season. Outside there were almost no free-grazing forage opportunities during the dry season, and inside the scheme there was only prosopis available during this time of the year. One could even say that prosopis was the reason that enabled these nomads to continue their nomadic lifestyle with large herds of livestock. One nomad leader owned 110 camels that fed during the dry season almost exclusively on the free-grazing forage in the New Halfa Scheme. In case this leader had had to purchase all the fodder needed for the camels, he would have been ruined economically in short time. No nomads appeared in the northern half of the New Halfa Scheme in the dry season, as there was no prosopis or other free-grazing forage available. The household survey conducted in the New Halfa Agriculture Irrigation Scheme for this study also revealed that the nomads sometimes used prosopis pods at least temporarily as emergency human food when a household had insufficient cash or no other food was available.

Table 13 synthesizes the share of prosopis and other environmental income out of the absolute total income of the nomad households. The nomads had large herds of livestock that fed on large quantities of free-grazing forage. Therefore, when the forage was not internalized into the household economies, the cash income share of the absolute total income was, on average, only 13%, while it was close to 60% when the forage was financially internalized. The nomads had no direct cash income from prosopis, but they had some small cash outlays from buying one-day portions of charcoal for their small stoves for making coffee.

### 5.1.2. Other impacts of prosopis on households in the framed area

Table 13 synthesizes the share of prosopis and other environmental income out of the absolute total income for all households in all the four population groups studied together in the framed area in New Halfa. Even when the forage was economically internalized, the average forest environmental income share exceeded 60%. The poorer households obtained, on average, some 10% of their cash from prosopis, while prospis was mainly a small net cash outlay for the wealthiest households. However, some tenant and landless share cropping households had additionally substantial costs from prosopis related to ploughing expenses and additional irrigation costs, as described earlier in the text above. An overall synthesis of prosopis impacts in the framed area is presented in Table 17 in Annex C.

Tables 14 and 15 in Annex C show the household utilization of prosopis and the vehicle tyre puncture expenses per each village and camp within the framed research area. Some fuelwood was sold from the framed research area to New Halfa town for bakery and household consumption. All available poles were consumed within the framed research area, and the household heads and other males who harvested prosopis stated that every bundle of fuelwood, pole or charcoal sack they produced could be sold.

Table 15 in Annex C shows specifically the prosopis charcoal production figures for the framed area. The main producers of charcoal were the western Sudanese landless who consumed part of their production by themselves but sold most of it to charcoal merchants and tenants. The larger part of the charcoal was sold to two outside merchants who had their respective representative located in tenant villages 3 and 33 next to the highway. The charcoal was resold from these stores and transported out of the area on large trucks along the highways to the major cities in Sudan and abroad through the harbour in Port Sudan. The data now collected in the villages enabled an estimation that totally some 51,400 sacks of charcoal were annually produced in the framed research area; of this, some 27,300 sacks were sold outside the area. The Debeira section management's official statistics indicated that some 25,000 charcoal sacks had been sold from the whole section area in the previous year (2002). Apart from the actual charcoal production and trade, there was also income generated for transportation business owners and their drivers, as well as a substantial amount of tax money for the state administration.

The Shukria, who lived about one kilometre outside the scheme, had to purchase most of their fuelwood, poles and charcoal from the scheme and probably also from the framed area. These nomads were not stationary in the framed area, but for about seven months they lived within the scheme and at least migrated through the framed area. The quantity of prosopis wood that the nomads used during this time came therefore from a larger area within the scheme, but as this particular area is the most densely invaded prosopis area of the scheme, it can be assumed that the major share of their prosopis wood (and particularly that in the form of charcoal) came from the framed area.

According to a few interviewed tenants, the lack of irrigation water for some remote fields was mainly due to the vegetation blocking the irrigation canals and minor elevation discrepancies between these fields and the main canal. The latter reason seems to have more to do with unresolved scheme design problems due to the flatness of the scheme area. The highest elevation point of the scheme is at 478.5 m in the south by the Khasm-al-Girba dam, while the lowest point is at 439 m at the northern end of the scheme – thereby the slope is just some third of a metre per kilometre of the scheme length. The outsourced maintenance of the scheme canals in Faras sub-section conducted in 2003 cost about 100 million SD, for lifting up 90,000 $m^3$ of silt and canal vegetation. The canal maintenance contractor stated that there had been very little cleaning of canals during the previous 7 - 10 years, although it should actually have been conducted every two to three years. This had probably increased the cost substantially as, for comparison, it can be mentioned that the general manager of the New Halfa Sugar Factory calculated for the company's own land a cost of only 10,000 SD per kilometre for silt excavating and canalside cleaning. On the sugar factory estate no livestock was allowed, which together with the annual efficient weeding reduced the expenses. Also the Shukria people were able to weed their irrigated lands with hired labour financed by their own individual small cash incomes.

One can estimate that prosopis roots inside the canal could maximally constitute the cause for some half of the total need for canal cleaning[5]. The other half would be caused by silt and the extensive growth of water hyacinth and other water weeds heavily infesting some of the canals. Based on the above information one could further estimate that prosopis could possibly cause canal clearing costs for some 15 million SD per year in Faras sub-section, while it would possibly cause some 5 million SD costs in Hagir sub-section, which is more distant from the larger canals. The total annual canal cleaning costs would thus be of a magnitude of some 20 million SD in the framed area.

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[5] This was, apart from my own estimate, also the figure stated by the local forester in the New Halfa Scheme.

Apart from the actual canal cleaning there was also a need for substantial canalside weeding and cutting of prosopis in both Faras and Hagir. In Faras the annual costs were of the magnitude of 6.4 million SD annually and in the whole Hagir slightly more. In the framed area part of Hagir the costs could therefore be some 5 million SD per year. The total annual canalside weeding and cutting cost would then be around 11.4 million SD in the framed area. The estimate is rough in the absence of detailed scheme statistics but provides the right magnitude of impact for an analysis.

In interviews with the scheme management it was stated that the scheme had also been experimenting with beekeeping in the prosopis-invaded areas. According to Mageed et al. (2001) the scheme had during the year 2000 collected 8,500 kg of honey from 29 beehives spread out over the whole area south of the New Halfa town. Five such beehives were in the middle of the framed research area, and these had provided some 2,100 kg of honey, which could be sold on the market in New Halfa for 2,200 SD/kg. The total value of this activity in the framed research area could thus potentially be 4,620,000 SD/year. It can be expected that prosopis flowers had a major share in the nectar production, although some natural acacias, agricultural crops and the orchard in the area must also have provided nectar.

The heads of 41 tenant households and 46 western and 22 eastern Sudanese landless households were interviewed in the framed area on whether prosopis is good or bad for them on a scale from “very good” = 1 to “very bad” = 5 and with 3 as the “neutral” value. For the tenants the average normative opinion value became 4.75, for the eastern Sudanese landless it was 3.82, and finally for the western Sudanese landless it became 2.41 (or slightly positive). The same household heads were also asked to give their opinion on whether prosopis is “beautiful” = 1 or “ugly” = 2. Again the tenants had the most negative opinion with the average normative value of 1.93, followed by the eastern Sudanese landless with a value of 1.86, and the western Sudanese landless were slightly positive with a value of 1.4.

Crop yields had declined overall in all sections of the scheme since the 1980s. The scheme lands of the framed research area in Faras and Hagir sections used to produce annually in 1985/86 and 1986/87 about 257 kg of cotton, while in 2002 – 2003 these fields produced only 151 kg (Hagir) and 130 kg (Faras) or 59% and 51%, respectively, of the yields in the 1980s. For all scheme sections the cotton yield range had declined from 211 – 317 kg/feddan in the 1980s to 130 – 235 kg/feddan in 2002/03. The present study did not go deeper into the causes of this overall crop yield decline, but it seems that it was a common trend and problem for the whole Sudanese agricultural sector. The problem has also led to an expansion of the farmland area wherever possible to counteract the effects of land degradation.

### 5.1.3. Comparisons between invaded and non-invaded sites in the scheme

In the northern parts of the scheme, one household interview and one group interview were conducted in each of the eight villages and camps assessed (Assoura, Geli, Geli Hadandawa, Sofia, Kambodin Kau, Jebel Aulia, Kareri, and Musnad Zuker). The distance between the framed research area and these northern sites was 55 to 70 km, and the northern villages were at a minimum distance of some 5 km from the nearest stands of prosopis. The results (cf. Table 16 in Annex C) are not statistically valid, but they suggest some trends worth mention. The western and eastern Sudanese landless groups tended to be, on an average, poorer than those in the southern parts of the scheme, with less cash circulating in the villages and fewer cash income alternatives. All the freely available vegetation appeared to have been either collected or consumed immediately by grazing.

A comparison between the framed prosopis-invaded part of the New Halfa Irrigation Scheme and the northern non-invaded parts clearly suggests impacts of prosopis on the respective micro-economies. Prosopis brought in substantial amounts of new money into the village (a micro-economy by its own), which raised the income level and enabled all-year round income generation, in contrast to the farming activities. Further, prosopis also influenced the labour wages in the scheme and diversified the income opportunities for the poorest population groups. There was almost no free-grazing dry season forage available for livestock in the barren area during the dry season, and, indicatively, there were therefore no nomad groups in this part of the irrigation scheme. The absence of livestock in the economy of the poorest landless population groups in the northern parts of the scheme may also have caused nutrition problems for these groups. They had to earn their living from lowly paid labour work in the scheme and to pay a high price for almost all household energy. Severe poverty was prevalent, which led to unaffordable education opportunities for the children and even to apathy. The only advantages for these population groups, as compared to those in the southern scheme parts, were the substantially lower levels of malaria incidence and the lower medical charges in the local health centre at the sugar factory. Tenant farmers in the north had only five feddans of crop cultivation land per household, but this land area provided them with a sufficient income that kept them financially floating and satisfied.

The scheme management stated that the northern parts of the New Halfa Scheme were towards the north increasingly drier, as the flow of irrigation water was insufficient there. There were also no shelterbelts in this part of the scheme, which meant that heavy winds were able to desiccate the land and blow sand into the area – thus further increasing the need for irrigation water. Some tree-based shelterbelts would thus have improved the microclimate in this part of the scheme.

### 5.1.4. Impact of prosopis on health in the New Halfa Scheme

In all tenant villages and landless camps in the framed area in the New Halfa Scheme at least one group of household heads (group size ranging from 3 – 20 persons) was interviewed on how many members of a household had suffered from malaria or schistosomiasis on a monthly basis during the previous year (one-year time slice). The household groups answered this either by giving one figure for the whole year (if every month had similar incidence), or by dividing the year into three seasons. The household incidence figures for malaria and schistosomiasis were in this way collected in the framed research area from a total of 15 villages or camps. In the case of schistosomiasis, all persons interviewed were of the opinion that everybody carried it on continuous basis. For malaria, the average monthly incidence varied between 46 and 100% per village or camp. The villagers stated that a person was, on average, ill with malaria for five days at a time. If a household head had been as frequently ill with malaria as any other person in the household, it would mean that, on average, he/she would have had approximately 11 times acute malaria during a year, which equalled 54 days of illness per year. This could be estimated to result in 15% less annual cash income, as compared to all-year healthy households. In addition, in most villages and camps it was stated that a few children below the age of five had died during the previous year due to malaria or a similar disease.

To compare the health situation between the prosopis-invaded framed research area in the southern part of the New Halfa Scheme and its non-invaded northern parts, interviews on health issues were conducted in eight villages belonging to Raira and Sedaira sections. The villagers of the northern parts of the scheme stated that all of them had schistosomiasis on a continuous basis, as the only water source people used was the schistosomiasis-infested canals in the same way as in the southern parts of the scheme. In contrast, the result for malaria incidence was much lower here than in the southern parts of the scheme. A household head would in the northern part of the scheme have malaria, on average, 4.4 times annually, which equalled 22 work days lost, or potentially some 6% loss in cash income for a household.

In many work activities other household members can act as stand-ins and it would not always matter, from the household income point of view, if the household head was ill for a few days. In contrast, in wage labour work where the household head has to do the work in person, illness with acute malaria would directly affect the household income. However, in the present study the share of prosopis in the increased malaria costs was not included in the financial analyses for the household incomes shown in Tables 1, 4, 7 and 10 in Annex C, as more in-depth research would have been needed to confirm these impacts on various kinds of livelihoods.

In interviews with teachers of one school in the framed area (Al Gurash near Village 33 with 253 boy and girl pupils) it was indicated that at the annual school start after the rainy season an estimated 60 – 70% of the children stayed at home with some illness, with malaria being the most common cause. Through personal communication with the medical doctors and surgeons[6] of the main New Halfa hospital it was clarified that in the southern part of the scheme the incidence of malaria was about 100% on a monthly basis for the whole population and that even the New Halfa town people had malaria at a likelihood of some 75% per month. The same doctors at the New Halfa hospital also stated that all people in the southern parts of the scheme had chronic schistosomiasis, while the town people had fewer incidences of this disease due to better water sanitation.

The 15 groups from all framed area villages and camps were further interviewed on the occurrence of prosopis thorn injuries during the previous year. In all five tenant villages combined the villagers were aware of 21 cases in which a person had had to seek medical assistance to clean an infected body part, and totally four cases of leg amputations were stated for the previous year. Through personal communication with the medical staff of the main New Halfa hospital it was further clarified that it is not the thorn in itself that causes the infection, but that a thorn injury becomes serious as a result of poor hygenic conditions. The hospital had, on average, five cases of severe thorn injury per week demanding repeated cleaning of wounds and medical treatment, which cost the patient totally about 18,000 to 20,000 SD in travel and treatment expenses. The doctors further confirmed that a few cases per year needed amputation of an infected extremity. The severity of thorn injury was in many cases aggravated by the treatment expenses which were unaffordable for poor people; this made the injured persons reluctant to seek medical treatment before the situation became acute.

Among the western Sudanese landless in the framed area there were some 45 cases of thorn wounds that needed medical attendance during the previous year. Additionally, two men had got a thorn in the eye while cutting prosopis, but no amputations of body parts had been done. Further, among the eastern Sudanese landless twelve cases of cleaning of wounds needing medical assistance were identified while no amputations were carried out for this group either. The question why the tenants were hardest hit in terms of prosopis injury needing amputations even when they were less than the other population groups involved in prosopis cutting could not be clarified.

The household groups were further interviewed on whether snake bites and scorpion stings had become more common after the invasion of prosopis. The household heads were asked about the previous year's snake bites and scorpion stings in comparison to the early 1990s. Even in the most densely invaded parts of the Debeira section snake bites were still very rare and scorpion stings

[6] Drs. Ageed Ayeid ElTohar, Amir Ahmed Salih, Yassir Mahmud Hamza and Mutaz Khojali.

numbered some tens per camp during the previous year. Earlier, however, the snake bite and scorpion sting incidences had been even rarer. Most snake bites had occurred after heavy rain when the snakes were forced to move up on higher land. Until the early 2000s the use of hazardous pesticides had been intensive in the scheme area (DDT was mentioned by several farmers), and, therefore, small rodents appeared not to be common in the area. This probably kept also the snake populations at a low level. The villagers stated that only in very rare cases did a person die from a snake bite, and the normal recovery time after a bite was 5 – 7 days, while a scorpion sting kept a person at rest for about two days. The medical staff at the New Halfa hospital stated that they attended about three cases of snake bite per week, and of those approximately three per month would end with the patient's death. The doctors estimated that in the whole scheme area there would be some 10 – 15 cases of snake bite per week, but most persons affected were not treated at the hospital at all.

Based on the above results one could conclude that the unchecked vegetation cover of which prosopis comprised a major part in the southern sections of the New Halfa Scheme had a clear aggravating impact on the incidences on malaria and thorn injuries, while it had no or only a low impact on the other health hazards assessed within this study.

### 5.1.5. Overview of prosopis impacts in the framed area

Figure 6 in Annex C shows the prosopis impact for the framed area in New Halfa such as the situation appeared after interviews, household and specific analyses, and impact screening processes. The overall impact of prosopis on the respective household groups varied, as there were clear differences between the population groups concerning the benefits and the social costs of prosopis.

Most of the above-presented calculations, descriptions and overviews of the impacts caused by prosopis in New Halfa have been set according to their respective magnitude of scale, so as to enable a comprehensive overview of the impacts. Table 17 in Annex C is an attempt to present all the main benefits and cost effects of prosopis in the framed research area in the Debeira section of New Halfa Scheme. The calculations include the economic values of benefits and costs to all tenants and the western and eastern Sudanese landless households living permanently inside the framed research area. The Shukria and nomad households were thus omitted, as the duration of their length of stay in the framed area could not be determined.

An overall Benefit/Cost Ratio of 2.1 is the outcome of the calculations using an economically internalized prosopis forage value. This value is based on the fodder efficiency from turning livestock fodder into meat and milk for human consumption. The fodder efficiency was calculated by dividing the annual livestock income by the corresponding annual total fodder amount. The overall fodder efficiency (31.5%) for all three population groups combined thus expressed the view of the local population on the usefulness of prosopis as forage. The total fodder consisted of own and purchased fodder, the free-grazing prosopis forage, as well as of other free-grazing forage. When the prosopis forage was incorporated into the benefit/cost ratio at its economically non-internalized value, the overall benefit/cost ratio amounted to 4.1. However, one has to bear in mind that this is not a proper TEV analysis, which is the case for the framed area in the Gandato Scheme to be presented in sub-chapter 5.3.

On the cost side of the calculation there was some uncertainty derived both from the small sample consisting of only 30 tenant households representing 2.4% out of a total of 1,240 households in the whole framed area. A substantial part of the health impacts was difficult to valuate credibly and would need further supporting focused research on monetizing of the health burden. These impacts were, for instance, related to the unchecked vegation and stagnant water contributing to the incidences of malaria, snake bites and scorpion stings which might not have required medical treatment but anyhow kept people at home from work or the school. It was difficult to get a full overview of how people protected themselves from malaria, as even the persons interviewed many times tended to be vague on this issue. There were also thorn injuries on both humans and livestock that were not included in the calculations, as these did not always require treatment. Most of the cost values were estimates derived from discussions with the tenants, the landless people, the scheme management and the professional experts, as presented in the previous sub-chapters. However, the detrimental impacts would have had to increase considerably before major shifts in the overall benefit/cost ratio would have taken place.

During the household interviews it was stated by a few persons from various hut camps and villages that in the late 1980s and early 1990s, just before the large-scale invasion of prosopis, the natural woody vegetation had almost disappeared in the neighbourhood. One western Sudanese landless person from the hut camp next to village 4 stated that the fuelwood in those days had to be collected at a distance of approximately 10 km. At the time of the interview in 2003, the village 4 and village 7 areas in the scheme were the ones most heavily invaded by prosopis. From this medium-term perspective it seems that prosopis appeared conveniently to compensate for a severe energy shortage that was building up in the area. In June 2004, field observations in the northern parts of the scheme confirmed that there was absolutely no woody vegetation in the vicinity of some of the assessed villages. All woody vegetation had been uprooted and used as fuelwood. Without prosopis this would most likely also have been the fate of the framed area (the old orchard and some eucalypt plantations excluded) in the southern parts of the scheme.

Prosopis shrub thickets were thus able to provide income safety nets for the survival of the poorest population groups. The fast and vigorous growth rate of prosopis was able to withstand a hard utilization pressure caused by people who struggled to make a livelihood from charcoal and cutting of fuelwood and poles. Any native acacia species would have been depleted in a short time period under such a utilization pressure, while prosopis could almost be seen as a non-depletable resource which provided income throughout the year for poor households. The access of poor people in New Halfa to prosopis tended to be open or informal, and the protection of their access to this or similar forest resource seemed to be vital for their well-being. With prosopis eradicated from the scheme, the state authorities would have had to create other livelihood opportunities for the landless population within and outside the scheme. The landless population groups had been allowed to use the prosopis resource without interference from the tenants or the scheme management because of the difficulties involved in achieving financial returns from it.

Table 18 shows that in the New Halfa Irrigation Scheme there was for most population groups a clear difference between the Gini coefficient for the absolute total income ($G_{AI}$) for each group separately and the Gini coefficient for all population groups combined. This means that the income distribution was more equal within the respective population groups than between them. The western landless population group included some wealthier households which had to some extent been able to rise out of poverty, which the Gini coefficient is also indicating.

Table 18. The income distribution between the surveyed population groups in the framed area of the New Halfa Scheme as measured by the Gini coefficient for absolute total income ($G_{AI}$) and the Absolute Kuznets Ratio (AKR).

| **Population group** | **$G_{AI}$** | **AKR** |
|---|---|---|
| Tenant farmers, New Halfa | 0.34 | 7.31 |
| Western Sudanese landless, New Halfa | 0.46 | 6.62 |
| Eastern Sudanese landless, New Halfa | 0.32 | 8.52 |
| Nomads, New Halfa | 0.42 | 11.80 |
| All groups in New Halfa, combined | 0.50 | 9.79 |

The income distribution differences can be visually shown by Lorenz curves as has been done in Figures 9 – 13 in Annex C, where each figure shows the situation for one particular population group or for all of them combined for the New Halfa Scheme. In the case where the prosopis and other free-grazing forage had not been fully internalized into the household economies, the annual forest environmental income would have shown an even larger share of the total annual income. The results shown in Table 13 complement those shown in Table 18. Despite the same size of the Gini coefficient, a comparison of the two tables indicates that the eastern Sudanese landless households had over 80% of all their income from subsistence sources, while the tenants had almost 80% of all their income from cash sources. The western Sudanese landless and the nomad households lay somewhere in the middle between the two other population groups. Parts of these two latter populations groups had been able to increase their cash income generation substantially, while the other households received most of their income from subsistence sources. This division of households into two groups can also be seen in the higher Gini coefficients and AKR values for the latter population groups.

Table 18 also shows the Absolute Kuznets Ratio (AKR) for the share of the absolute total income of the wealthiest 20% of the households of each population group in comparison to the same share of the poorest 20% in each group. For the New Halfa case the income distribution was more even for the tenants and the western and eastern Sudanese landless groups, while there were greater distribution differences among the nomads. The income distribution discrepancy for the total population of the framed area was slightly higher than that for each respective group, except for the case of the nomads.

## 5.2. Welfare situation in the Gandato Irrigation Scheme

### 5.2.1. Structure of household economies and socio-economic settings

**Economic income structure of the households in the framed research area.** The other framed research site some 9 to 16 km south of Shendi and about 110 km north of Khartoum was quite different from the New Halfa Irrigation Scheme site. The riverine area along the Nile has probably been settled for thousands of years. The Gandato Irrigation Scheme had been in operation since 1917, and the scheme land had been inherited in the same families since the start-up. For the framed research area in the Gandato Irrigation Scheme, all 70 household interviews from four villages (Al Hosh, Dueimat, Al Figaiga and Wad Killian) were analyzed together, as there were for most economic activities only small differences between the villages or between people of different ethnic backgrounds. The size of the statistical sample of interviewed households from the framed area of the Gandato Scheme was 5% (70 households interviewed out of a total of 1,390).

Table 19 in Annex C shows that only for the two wealthiest income quintiles 4 and 5 and in a few households in the poorer quintiles crop production was profitable. For many poorer households it just provided the basic subsistence with sorghum or okra. This can be seen from a higher subsistence income in the poorer income quintiles.

Most of the households currently had less livestock than a decade earlier, as there was not much freely available grass for grazing. In the Gandato Scheme there was substantial fodder production which actually gave the farmers a good and stable monthly income when sold. The farmers had faced substantial costs for the establishment of alfalfa fodder production but were then able to obtain fodder on a continuous basis for four years if the irrigation water was secured. After that the household would cultivate another type of crop. Livestock was mainly kept for producing fresh milk for family subsistence use and sometimes for sales of animals, but some few households also sold milk and generated income from it. For most households with livestock, the main expense came from buying the fodder, which caused livestock rearing an overall loss in case milk for sale could not be produced in sufficient amounts. To keep livestock for meat only was not profitable if much of the fodder had to be purchased.

Totally 36 out of the 70 households interviewed in all income quintiles had unskilled or skilled labour cash incomes, and these income sources did actually constitute a larger share of the total household income than that from agriculture in most of the cases. Closely related to the labour wage income was also the small-scale trade income (earned by petty vegetable sellers, petty shop owners, and part-time tailors, etc.). Seven households interviewed earned in this way an income that was of the same magnitude as the labour wage income. In addition, eleven households had a substantial regular trade income (from butchery, milling, village shops, livestock trading, crop middleman trading, etc.), which put most of these households in the top income quintile. In all income quintiles there were also a few households (totally 17 of 70 in all cash income quintiles) that received substantial private cash remittances from relatives elsewhere or state pension from earlier governmental work. Reported household costs covered items such as liquid gas for cooking, drinking water, electricity, children's education costs, telephone expenses and, for two interviewed households, also the daily transportation costs between Wad Killian and Shendi, where two male household heads worked.

**Socio-economic background of the population.** The framed area on the eastern bank of the Nile consisted of the large village of Al Hosh with 850 households, which actually was divided into seven separate parts (Banat al Hamda, Hosh al Hag, Hosh Wad Nura, Bagaria (Hassania), Ed Dem, Hellat Wara, and Hellat Giddam). Additionally, the framed area contained two smaller villages, Al Dueimat with 120 and Al Figaiga with 65 households, respectively, which also belonged to the riverine agricultural area as part of the Gandato Scheme. The household survey and subsequent financial analysis further included one additional large and spread-out village, Wad Killian, with 280 households, which lay further away from the Nile. Households in Wad Killian did not have tenancies in the Gandato Irrigation Scheme, and the villagers had so far had mostly rainfed farming available for them. Al Hosh and a small part of Wad Killian did not have any prosopis shelterbelt against a large open, completely bare area from which invading sheet sand was blown into these villages. The rest of Wad Killian, Dueimat and Al Figaiga were protected by shelterbelts of prosopis and a large bufferzone of land on which prosopis had been invading. Between all the above-mentioned villages lay still a fifth village, Tundub, which was left out from the household survey as explained in sub-chapter 4.4.2.

Table 20 in Annex C illustrates the socio-economic background of the people of this framed area. The Gandato Scheme tenant villages (Al Figaiga, Dueimat and Al Hosh) mainly consisted of people of the Gaalian and Shaigyan ethnic groups, but a few Bederi, Mahasi, Ababda and ZuAdab households were also interviewed. The Gaalian and Shaigyan households had been settled farmers for a long time, and during the last three to five decades the former pastoralist ethnic groups of Ababda, ZuAdab and Hassan had also settled in the area. They lived now in some parts of Al Hosh or in Wad Killian and Tundub further away from the river. These people had had to change their lifestyle from pastoral to agricultural, as the climate had been slowly changing and declining amounts of grass were available for their livestock to graze.

**Direct impact of prosopis on the Gandato Scheme household economy.** As shown in Table 21 in Annex C, almost every single household in the framed area had more costs and cash outlays than cash income from prosopis. Many households purchased at least part of their fuelwood and poles, and all their charcoal, although they could have collected the two first mentioned items free. The tenant farmers' weeding costs in the Gandato Scheme farmlands were true social costs of prosopis. In the household survey the villagers in the framed research area in the Gandato Scheme stated that prosopis poles did not last for more than one to two years due to termite attacks.

Table 13 in Annex C shows that an economic internalizing of the free-grazing forage incomes for the households does not fully accredit prosopis and other environmental incomes for their respective roles for the income generation in the Gandato Scheme. The overall benefit from prosopis and other environmental incomes to the household economy in the Gandato Scheme was about half of the absolute total income when the forage was not economically internalized, while it was only 10% when the forage was internalized.

### 5.2.2. Impact of prosopis on health

Health-related questions similar to those in the New Halfa household survey were also asked from the Gandato Scheme households. The results were based on 15 group interviews with 3 – 15 household heads in each group. The groups were asked, among other things, about the incidence of malaria and schistosomiasis on a monthly basis during a one-year period in each specific group's neighbourhood in the Al Hosh, Dueimat, Al Figaiga and Wad Killian villages, respectively. The results were somewhat inconclusive for malaria, as there were no clear trends in any direction among the villages. Each of the group answers was either an annual one-household malaria incidence value on which also the other household heads in the group agreed, or a compromise on the various households' malaria incidences derived at in the discussion. No one reported to suffer from schistosomiasis in the whole framed area in the Gandato Scheme.

According to the responses from all 15 groups, the monthly incidence of malaria for an average person during a year was $0.17 \pm 0.15$. For open areas and those protected by prosopis shelterbelts, the average monthly incidences were equal with this estimation accuracy. On an annual basis this means that the average person fell ill with malaria approximately twice. Judged from the interview results it would appear that the incidences of malaria would have more than doubled during the last decade in this area and that vicinity to wells may have had some impact on this. Another observation was that the unprotected Hassania population in Al Hosh, the unprotected Wad Killian group, and the group nearest to the well and the sand invasion frontline area in the main Wad Killian village stated 0.27, 0.39 and 0.37 monthly average malaria incidences, respectively. These households also seemed to be highly vulnerable to sand invasion-stress and poverty, and their resistance to diseases may therefore have been lower than that of other households in the framed area. This coarse health survey could not properly differentiate between malaria and other similar diseases but gave anyhow an indication of the situation as seen from the local population’s point of view.

Local medical doctors were also interviewed concerning malaria incidences in the area. One from the Tundub hospital stated that there had been malaria throughout the previous year in the area and that the peak seasons for patients with malaria at the hospital had been January - February and August. Fewest malaria incidences had occurred in November, June and July. The Shendi main hospital had treated some 2,000 malaria patients per month, and of these some 500 patients annually were considered severely ill and in need of strong medication. Patients came from an extensive area surrounding the town.

While conducting the household survey in the unprotected poorest part of Wad Killian which consisted of 30 households on the bare sandy land, another telling observation was made. All persons who came for the group interview session were young. The most senior males were below 40 years of age, and no older males were seen. An elder woman who appeared ill was sitting outside a house some 80 m away gazing at the interviewing session. All the other approximately 20 women who came to greet the female Sudanese foresters acting as interpreters were in their late teens, twenties or thirties. The significance of this passing-by observation was not realized at the time, but afterwards, during the analyzing of the data, did this overall image of the community situation become clear. As this was only a casual observation, a decision was taken to refrain from quantifying or monetizing the complex and obviously substantially reduced life expectancy situation in the whole sub-village.

The villagers in the Gandato Scheme stated that there had been only few incidents of snake bites or scorpion stings in their community and these had mainly been confined to the riverine zone rather than the prosopis buffer zone or the shelterbelts. Worth special mention was that there were no serious thorn injuries identified in the area during the financial year 2002 – 2003.

### 5.2.3. Overview of the prosopis impact on household economy

Figure 8 in Annex C shows the prosopis impact for the framed area in the Gandato Scheme as the situation appeared after interviews, analyses and impact screening processes. The main environmental goods and services derived from prosopis appeared to be linked to shelterbelts, the free-grazing forage and the utilization of prosopis wood and NWFPs (comprehensive shelterbelt impacts are presented in more detail in sub-chapter 5.3.). Al Hosh village did not have much prosopis on its land, except for some inside the agricultural fields and the village itself, where the tree did not belong, and therefore the benefits were much more limited than the ones found in the other villages of the framed area.

The great majority of all the 70 households interviewed used substantial amounts of free-grazing forage for their livestock. The average annual subsistence contribution of prosopis fodder to each household was worth 205,000 SD as a financially internalized and monetized value. Prosopis constituted a net cash expense and cash outlay for almost all households, and the respective income quintile 1 to 5 averages varied from 14,000 up to 42,500 SD. This expense and cash outlay included for many households the purchase of fuelwood, poles and charcoal, but also the weeding of prosopis in irrigated agricultural fields. The weeding expense was, on average, approximately 9,440 SD per year if spread out over all 70 households, or 27,542 SD when calculated for the actual households that did have weeding labour costs. This figure did not include the own household labour cost for this activity, since all internal labour costs in agriculture were omitted.

Each of the 70 households interviewed used, on average, 471 bundles of fuelwood, 6.2 sacks of prosopis charcoal and 13 – 20 prosopis poles of variable size per year. Apart from the prosopis-based energy, the wealthier scheme villagers also increasingly had both electricity and liquid gas as energy supplement. In Wad Killian there was no electricity, and only a few households even used liquid gas. A container filling of gas and a sack of charcoal cost about the same in the Shendi area, so it can be foreseen that the gas consumption will steadily continue to increase. Household surveys identified only one household that admitted that it sold fuelwood in the framed research area (there was a tax on selling more than 10 bundles per day). Interestingly, however, 21 out of the 70 households interviewed stated that they purchased at least part of the annual fuelwood consumed.

Due to the fact that significant numbers of households are leaving the Al Hosh for good, social visits were becoming a heavy burden for most of the villagers. The trend will be increasing to a point where almost all close relatives from some clans have moved away. This had already happened to some extent, and groups of kin households could be found in both Shendi and Khartoum suburbs. For others, the social visit traveling will still increase in the future and, particularly for the poorer households, the available annual cash income will fairly directly determine how many annual visits they can afford to Khartoum or even the near-by Shendi.

For the Gandato Irrigation Scheme the Gini coefficient for the absolute total income was 0.52, which indicates a level similar to that for all population groups combined in the framed area of the New Halfa Irrigation Scheme. This suggests that the income distribution in the framed area was fairly uneven, as some households had better been able to increase their wealth in various businesses. The environmental income did still substantially impact on the absolute total income level, but *it was not redistributed among the households*, as almost all households got benefits from prosopis. Actually this means that *the benefits were quite well distributed among the households*. Figure 14 in Annex C shows a combined Lorenz curve for the whole population group in the framed area of the Gandato Scheme.

The Absolute Kuznets Ratio (AKR) for the Gandato Irrigation Scheme was 15.39 and suggests a much more pronounced difference between the poorest and wealthiest 20% of households, in comparison to the New Halfa case. Furthermore, in the Gandato Scheme prosopis was to a lesser degree a cash income source. Prosopis weeding in the fields as well as the purchase of fuelwood and charcoal were, for many households, costs and cash outlays, rather than income.

### 5.3. Results from the TEV study in the framed area in the Gandato Scheme

#### 5.3.1. Outline of the TEV study

All the financial analyses results presented in sub-chapters 5.3.2. – 5.3.14. are eventually summarized in Tables 31 and 32 in Annex C. The tables comprise a comprehensive TEV synthesis including 19 main benefit/cost categories for Scenario A (i.e. the current situation with prosopis externalities). It is further compared with the same benefit/detriment categories in Scenario B (the situation where prosopis is absent from the area) in accordance with Pierce's equation presented on page 37. The third Scenario C is also included, showing the outcome if prosopis would cover the whole framed bufferzone area outside the actual irrigation scheme. To facilitate understanding how the figures in Tables 31 and 32 have been calculated, each part of the financial analysis will first be outlined below and separately also presented in the tables of Annex C.

### 5.3.2. Externalities and other impacts in relation to sand invasion on homesteads

The household economic surveys for the Gandato Scheme also included questions regarding sand invasion. Totally 29 individual households were interviewed that had sand invasion problems themselves and, additionally, four group interviews were conducted in village parts along the open sand fringe in Al Hosh, Tundub, and Wad Killian concerning this topic specifically. A synthesis of these answers is compiled into Tables 22 and 23 in Annex C. Further, it was clarified also with the remaining individual households interviewed how many social visits they had made the previous year due to the resettlement caused by sand invasion. Information on resettlement activities during the previous decade basically provided a triangulation point for the estimation of the Scenario B situation. During the financial year June 2002 to July 2003, Dueimat, Al Figaiga and the main parts of Tundub and Wad Killian were protected from sand invasion by prosopis shelterbelts and a bufferzone with self-spreading prosopis. The main sand invasion problems were thus confined to parts of Wad Killian and Tundub, as well as to almost the whole of Al Hosh.

Tables 22 and 23 in Annex C depict the situation in Al Hosh and Wad Killian by all village parts separately, as the inhabitants of both villages seemed to know best their own specific part of the respective villages. It was difficult to distinguish all the different village parts from each other, as these had often merged with each other and the division was now often merely a conceptual one. The household survey information was further triangulated both with own field observations and with interpretations of GPS-improved Landsat satellite images. The tables also show the occupational profiles of those household heads who were potential leavers for Khartoum and Shendi. Emigration of whole households only occurred from Al Hosh, while the men who left from other villages for outside work kept their families in the villages during their absence which could last for several years, with a few home visits each year. Mainly the members of the Gaalian and Shaigyan households left for Khartoum, while the Ababdas and the Hassanians remained and endured the sand invasion or in some cases moved to Shendi. The latter were former pastoralists settled permanently during the last decades and did not have relatives in the cities who could support resettlement. The fact that the decision often was difficult for them is illustrated by an account on resettlement presented in Annex B.

The annual emigration from Al Hosh for 1992 – 2003 was estimated based on the interviewed persons' perception of the situation. From 1992 to 2003, some 120 households had permanently left Al Hosh for Khartoum (77 households) or for Shendi (43 households). For the financial analysis presented later in the study, the value accrued for the fiscal year June 2002 to July 2003 was calculated as the average of emigrating households for 2002 and 2003.

As presented in the methods chapter, the housing costs per household were derived from the actual household interviews, which were then categorized by house location and the severity of sand invasion impact. The 25 household interviews conducted in Al Hosh were profiled, and nine of them indicated direct sand invasion, while the remaining households were not directly affected. This rate of nine households out of 25 was approximately the same percentual share as the actual total estimate of 325 sand-invaded households out of the whole Al Hosh household community (i.e. 850 households). The derived estimates for the annual loss in accommodation quality, sand excavation cost, as well as the annual house rebuilding costs were therefore separately calculated for each individual household interviewed in all the villages for the Scenario A case (i.e. the current situation with prosopis externalities) and then extrapolated for the rest of the households in each village. The results of the financial analyses on the effects of sand invasion on housing were directly transferred into Table 31 in Annex C. Results for Tundub were also included and calculated as described in Chapter 2.4., mainly using the data from the profiled 26 non-tenant households of Al Hosh, Dueimat, Al Figaiga and Wad Killian as average proxy data.

Regarding the Scenario B calculations, many sources of information were considered and subsequently attempts were made to estimate a situation which did not currently exist in the framed area. For Al Hosh the situation was the same as in Scenario A, but for all other villages the situation was revised so as to cover the hypothetical scenario that prosopis had been eradicated from the framed area. Some household interviews in Wad Killian, Al Figaiga and Dueimat provided information on the situation in these villages before prosopis had been planted in shelterbelts and begun to spread into the bufferzone area. The current bufferzone area had been relatively devoid of vegetation then, and substantial sand invasion had occurred in all the villages. In Wad Killian it was said that at least 50 houses had been completely broken down each year out of the total of 170 that existed in the main village part in 1990-1991. In Al Figaiga it was stated that severe sand invasion had occurred only some 10 – 15 years before the household interviews were conducted. This could indeed be confirmed through own field observations in the Al Figaiga village area. Loose sand had piled up in many places around the village, and the shelterbelt next to the irrigated scheme land was standing about 1 – 1.5 m above the ground level on both sides, which showed that sand had been trapped inside the prosopis shelterbelt stand. In the fields next to the shelterbelt it could also be easily seen and assessed through soil analysis conducted for this present study that sand had blown into the fields before the shelterbelt had started to protect them.

The Dueimat village outskirts had large amounts of loose sand lying around, and, on the northern side between the village and Tundub and Banat al Hamda (part of Al Hosh village), a large area of the scheme had been severely invaded by large amounts of sand. This area was still almost devoid of vegetation, although prosopis had started to invade it. These observations could also be confirmed by Landsat satellite images from 1972, 1987, 2000 and January 2004. It could thus be concluded that severe sand invasion was likely to occur without a protective buffer zone of prosopis in the whole area. By using the GPS-improved satellite image from January 2004 as a map, rough estimates could be calculated on how a large part of each village would be invaded by sand without the protecting shelterbelts. Furthermore, it was roughly estimated, based on the household interview result for each respective village part separately, that many households could not afford almost annually rebuilding their entire houses; instead, they had at least a properly built one-room or one-and-a-half-room house. In Al Figaiga, Dueimat, Tundub, and, for a few families even in Wad Killian, there were also two-room houses of which most, however, would be without verandas. The great majority of the remaining houses, in particular in Wad Killian, would be single-room houses of poor construction materials worth about 20,000 SD. The above-derived rough estimates were eventually used in Table 31 in Annex C for the Scenario B calculations for the whole-village financial analysis.

### 5.3.3. Impacts in relation to improvement in microclimate for agriculture

The shelterbelt protection effect for the microclimate for agriculture is difficult to distinguish in an empirical situation as compared with how shelterbelts perform in controlled experimental research field trials. Many challenging deficiencies were thus encountered in the Gandato Scheme that probably diluted the impact. The overall assumption was that the crop yields per feddan in both groups would generally be the same, and further that protected fields would then produce higher crop yields per feddan. The analysis indicated, in accordance with the assumption, that the protected Al Figaiga/Dueimat irrigated fields actually produced more, on the average, per feddan than did the unprotected Al Hosh fields. The quantitative field productivity results are presented in Table 24 in Annex C and cover an analysis of protected 77 feddans from the Al Figaiga/Dueimat fields and 45 unprotected feddans of the Al Hosh fields. These analyzed protected or unprotected areas were otherwise cultivated in similar fashion in terms of well or pump water, labour, fertilizer and plouging, and could therefore be compared with each other.

Complications were first encountered in the form of hugely variable crop selling prices stated, in particular, in the Al Figaiga and Dueimat villages. The selling prices for onions - an important crop in all villages - ranged from 4,000 – 8,000 SD per sack in the above-mentioned two villages, while it ranged from 6,000 – 8,000 SD in Al Hosh. The average selling prices in Al Hosh were substantially higher than those in the other villages both for onions and broad beans. The average gross margin income in Al Hosh was therefore a little higher (55.6%) than that in the other two scheme villages (51.7%). As more onions were grown in Al Hosh and as it had a substantially higher per-feddan gross margin income possibility, the yield differences for onions (43.9% more in protected fields) and for beans (50.0% more) were thereby financially more or less evened out. For fodder, on the other hand, the same price per each fodder bundle was obtained in all the villages, and therefore it was clear that some 13% more fodder per feddan could be produced in shelterbelt-protected fields. For crops such as mangoes, vegetables and soybeans no comparative pair could be found in the other village category, whereby these crops were omitted from the analysis. This meant that only 72 feddans of protected fields and 34 feddans of unprotected fields were eventually included in the externality analysis.

From the Landsat satellite image from January 2004 it could be seen that large parts of the fields adjacent to Al Hosh village were much drier than the protected fields in the scheme land of the other villages or the fields closer to the Nile. Based on estimations from the satellite image and on the field conditions, some 40 ha or 96 feddans would have consisted of severely desiccated farmlands that in fact were fields least protected from sand invasion and winds and adjacent to the Al Hosh village. The desiccated uncultivated fields had the same grey colour in the Landsat satellite image as the bare sand lands, while the protected uncultivated fields appeared much darker (cf. the map of the area in Figure 4 in Annex C).

Reasons behind the different prices of the same crops in Al Hosh in comparison to the other two villages were several. In Al Figaiga and Dueimat, a substantial part of the crop production was sold to middlemen, while the Al Hosh tenant farmers were selling their produce directly in the larger Al Hosh community or as middlemen themselves for other markets. The great majority of the Al Hosh households did not have their own irrigated farmlands, and thus a substantially larger share of the total produce in Al Hosh was consumed locally. The Al Figaiga and Dueimat tenant farmers earned annually, on the average, less than did the Al Hosh tenant farmers, and this meant that onions, which were the most labour-intensive crop to grow, were for many farmers too costly to grow on a larger scale in Al Figaiga or Dueimat, as the tenant households' cash money was almost used up before the new harvest. The alfalfa fodder was consumed locally, and here the local market price was the same in all the villages, whereby the better markets and fodder yields in the protected villages was directly reflected in the income.

To bring the crop yield differences of protected and unprotected scheme parts back into a financial analysis where the empirical profit differences could be distinguished, the total annual village cultivation statistics from four financial years (1999/2000 to 2002/2003) was used, as shown in Table 24. First the four-year averages of annual crop fields in the protected and the unprotected scheme fields, respectively, were calculated. This stage included also a scaling of the protected fields to the same land area as used for the unprotected fields. In both categories there was about ten percent of the total area used for mangoes, vegetables or soybeans, and, as there was no corresponding product in the other category, this ten percent of other crops was disregarded.

Instead, the area used for onions, beans and fodder (90%) was scaled to cover the full 100% of the field units analyzed. The mango, vegetable and partly soybean fields were located close to the river, which also in this respect made them less interesting from the analysis perspective, as the shelterbelts were least affecting the land closest to the river.

For the financial analysis the actual crop selling market prices of onions and beans were first calculated per land area for protected and unprotected fields. Then a middle price (average of average field unit prices of both categories) was used for both crops in the final externality calculations. This meant that the price used in the financial analysis for protected fields became a little higher and had for the unprotected fields a field unit price somewhat lower than the actual average for the respective categories.

The financial analysis first aimed at calculation of the income reduction per feddan in the unprotected fields in comparison with that for the protected ones. It was found that the protected fields produced, on average, 12,876 SD more worth per feddan when scaled according to the total village crop diversification. Additionally, there were fewer field units under cultivation in Al Hosh fields, which could also be seen from the satellite image. The gross income difference then became 23,450,975 SD for the farmland of the whole village. This figure represents the Scenario A situation with prosopis shelterbelts in half of the total area. For the Scenario B situation, with prosopis absent in the whole area, the shelterbelt effect of the protected fields was hypothetically left out, and now the Al Figaiga/Dueimat fields produced 18,760,780 SD less worth of crop yield than those in Scenario A. This was simply calculated as 80% of the Al Hosh (or unprotected fields) crop yield income reduction, as it was not known what really would happen to the crop composition or prices in case the Al Figaiga/Dueimat fields became unprotected and the crop yield thus diminished.

### 5.3.4. Income losses due to sand invasion-induced social visits

In Al Hosh village the households faced an income loss due to social visits to relatives and friends who permanently had resettled in Shendi or Khartoum. The work time lost due to social visits caused annually a one-percent gross margin cash income loss for the average-income household in Al Hosh. On the other hand, households lost much more of their annual cash income on the actual travel expenses between Khartoum and Shendi to visit their relatives and friends. For the average-income household, the actual social visiting expenses from sand invasion-induced resettlement caused an annual gross-margin cash income loss of about 8% in Al Hosh. The synthesis of the above has been included in Table 31 and 32 in Annex C.

### 5.3.5. Impacts on health and mobility

As explained in the methodology sub-chapter 4.4.6., health and some other impacts were estimated using a shadow project which in Scanario A was based on the establishment of new prosopis shelterbelts between Wad Killian via Tundub to Banat al Hamda and further to the northern end of Al Hosh (see the line drawn between the relevant villages shown on the map in Figure 4 in Annex C). Goats and other livestock were to be kept away from the shelterbelts until the trees had reached about 2.5 m in height. Properly irrigated under favourable soil conditions, prosopis could reach a height of 4 m in nine months in the Shendi area. Shelterbelt trees were assumed established in at least three rows 3 or 4 m apart, with 2 to 3 m in-row spacing. The rows were assumed established on ridges, between which the furrows were used for irrigation.

In Table 25 in Annex C the expenses of this shadow project have been calculated using relevant plantation establishment and management costs as described in sub-chapter 4.4.6. During the rainy season parts of the shelterbelts could have been irrigated also by the diverted rainwater runoff, but one cannot rely in advance on the availability of rainwater. This situation should thus be seen only as a potential money-saving opportunity.

### 5.3.6. Impacts in relation to livestock rearing

**Changes in livestock numbers per individual households.** Figures on impacts of prosopis forage on local livestock rearing are shown in Table 26 in Annex C. The household survey indicated that, in 2003, a higher number of households than approximately ten years before had livestock, but the number of livestock per household had decreased by about half during the same period. The estimate for household livestock numbers for “approximately ten years before” is about the same magnitude as the one concluded by ElRahman (1991) in his survey from 1989 which covered 100 households in the Zeidab Irrigation Scheme some 80 km to the north along the Nile.

The present study further analyzed how many annual livestock feeding units the interviewed households had in the framed research area. The results were calculated as described in sub-chapter 4.3.2. and they are shown in Table 26 in Annex C.

Contrary to the current declining livestock population trend for most households in 2003, there were a few households which had specific commercial interest in livestock rearing. These and similar households in the neighbourhood had substantially increased the livestock populations in the region and thereby heavily affected the official statistics on livestock populations. According to these statistics for 2000 – 2002 compiled by the Federal Ministry for Range Management in Khartoum, the populations of cattle, sheep, goats and camels were on the increase in the River Nile State by some 2 – 4% annually. Without prosopis forage this would have been almost impossible. Linked to the above was also the fact that households cultivated or purchased a larger share than before of the annual fodder needed for their livestock, and, therefore, most households owned fewer animals than before to cope with the accumulating fodder expenses.

It was also calculated how many livestock feeding units the households could afford in case no free-grazing prosopis forage would be available. For wealthier households with few heads of livestock it was not an issue, as they in many cases already fed their animals only with commercial alfalfa. In these cases there was not much reduction in livestock numbers. For the great majority of the households, however, the prosopis forage was an extremely important part of the annual fodder supply. The share of different kinds of fodder in Al Hosh, Al Figaiga/Dueimat and Wad Killian is shown in Table 27 in Annex C for Scenario A as well as for Scenario B. In the Scenario A case the share of prosopis was half of all fodder in the framed area, and together with the other free-grazing fodder it corresponded for about two thirds of all the fodder used annually. If additionally the free-grazing fodder in the uncultivated fields and in the remote wadi valleys were taken into account, then 76% of the fodder was some kind of free-grazing forage, leaving only a 24% share for commercial fodders.

In Scenario B the prosopis grazing was set to zero and the lack of prosopis then also reduced other free-grazing opportunities, whereby only 32% would be other than commercial fodder. The total amount of fodder in the Scenario B case was about half of that in Scenario A. This would significantly constrain the poor households from having more than one goat. The outcome for livestock per household in Scenario B is also shown in Table 26 in Annex C. The drastically reduced numbers of various livestock would certainly have affected the income generation potential, but the extent of that effect was difficult to determine without further studies.

**Livestock forage as public good.** The financial analysis also included a study on how much it cost in fodder expenses for the households in the community to produce the meat and the milk consumed in 2003 both in Scenario A and in Scenario B. The Scenario A situation may not have been the ideal optimum for each household, but it was a fairly balanced situation where the households still paid, on average, only 24% of the annual fodder costs themselves. On the other hand, the Scenario B situation, with some 45% less livestock, represented a situation far from ideal. The public good support from prosopis for maintaining the same amount of meat and milk production as in Scenario A could be calculated through the much increased commercial fodder costs required to keep the same numbers of livestock in a situation without the tree resource. Table 31 in Annex C shows the loss in public good of almost no free-grazing forage on meat and milk production for each village in the framed area.

**Milk and meat prices in Scenarios A and B.** The meat and milk prices in Scenario A were both lower and more stable than those in Scenario B which assumed less livestock in the framed area villages. It is impossible to know how much higher the prices would have been in the Scenario B situation, as it would have required knowledge of the size of the area from which prosopis would have been completely eradicated in Sudan; for instance, whether it had been the case just for the framed research area, the whole province, or the whole of arid and semi-arid Sudan. In case it would have been just for the framed research area, there may not have been much change in prices. The framed area households may have demanded a little less meat and milk, and the prices in the area would have slightly increased to cover the short-distance transportation costs that would have accrued on top of the own village production. In case prosopis had been eradicated from the whole River Nile State, then livestock could have continued to be transported alive from the central parts of Sudan with some feed and slaughtered at the destination in the villages in River Nile State, or canned meat and milk powder could have been purchased from elsewhere in Sudan. In this case the transportation and animal feed costs during transportation would have increased the prices to some extent. In case prosopis had been eradicated from the whole of the drier parts of Sudan, it would have caused a tremendous strain on the natural vegetation over extensive areas in Sudan and eventually led to an unsustainable situation. This would have caused extremely high externality costs for the future, especially if also the effects of climate change were considered. The foreseeable extent of over-grazing would have made all climate change mitigation efforts useless.

**Impact of reduced animal protein consumption.** A reduced intake of animal protein in the diet would reduce the capacity of farmers and other heavy working adults to work efficiently. Heavy-working males usually require approximately 1-1.5 g/body kg of animal protein to endure long-term efficient working (Pietilä 1996). In case the animal protein intake is reduced it could mean a slower working pace and longer working days for the farmers, or employment of more field workers, and thus indirectly lead to reduced income.

### 5.3.7. Conservation of the native woody vegetation and impacts from utilization of prosopis

**Fuelwood, poles, charcoal and conservation of the native acacia vegetation.** It is obvious that in Sudan the indigenous acacia vegetation on drylands is not able to endure or fully mitigate the detrimental combined effects of climate change and human and livestock population growth pressure. In particular, the local acacias cannot stop the sand dunes or sheet sand from moving into villages, fields and pastures. For instance, *Acacia tortilis* lifts its crown up several metres above the ground, and the single thick bole does not provide much hindrance to sand movement under the crown. The growth of the native tree stands is also so slow that they easily become depleted around villages. On the other hand, prosopis is growing at such a rate that the villagers are not able to deplete the stands without heavy machinery or concerted efforts. Rather, prosopis stands in most places only grow denser as they are used. In this way a fairly small area of prosopis is able to provide a village with all the fuelwood and fodder it needs in one area and thereby spare the remaining adjacent native acacia vegetation. Prosopis thus has a role in environmental conservation of the native woody vegetation in River Nile State if seen from a holistic and objective perspective.

According to ElRahman (1991), already in 1989 almost all of the fuelwood used in the Zeidab irrigation scheme was derived from prosopis, as most native tree species had been depleted around the villages. From Landsat satellite images dated 1972, 1987, 2000 and 2004 it appears that not much native woody vegetation had existed in the Gandato framed research area since the early 1970s. In 2003 all the fuelwood used there was from prosopis. Prosopis also seemed to occupy an ecological niche in areas where no other tree species are able to withstand the harsh sand invasion in combination with its tolerance to the saline groundwater at 10 – 20 m depth. The loose sand accumulating all the way from Banat al Hamda (part of the Al Hosh village) to Tundub and Wad Killian and from there to the southwest provided suitable sites for prosopis to establish itself.

Table 30 in Annex C shows the value of prosopis fuelwood in the framed research area. Staff persons from each of the village bakeries were interviewed on the use of fuelwood, and the household surveys provided information on its domestic use of fuelwood. The daily fuelwood was often collected in two bundles of totally about 1.8 kg, which had a price of 50 SD. As the villagers were accustomed to estimate the size of a bundle it was possible to convert the wood amounts directly to money terms. All prosopis fuelwood and poles, regardless of whether they had been purchased or collected, were calculated as benefits from prosopis. Due to the difference in size of the sustainable collection area between prosopis and native acacia stands, a multiplier of five was added to the financial externality analysis, as described in sub-chapter 4.4.8. For charcoal, which also was almost all derived from prosopis, only a +1 multiplier was used since it came from areas outside the state where prosopis needed to be controlled in agricultural fields and elsewhere, as also described in sub-chapter 4.4.8.

In Scenario B the local native acacia stands would have been depleted, which was a detrimental environmental effect and thus the sign of fuelwood and pole use is negative as described in sub-chapter 4.4.8. Charcoal was still thought to come from the same sources and had therefore a positive sign in the financial externality analysis.

**Use of prosopis in fencing and as animal shades.** The inclusion of fencing and animal shade from prosopis in the financial externality analysis was straightforward. In the fencing situation, the total length of fences from thorny prosopis branches was based on a Landsat satellite image from January 2004 and on own field observations. Values presented in Table 31 in Annex C are substituted with barbed wire fencing costs divided by five, due to the poorer durability of fences made from thorny branches. In the absence of prosopis, animal sheds were needed to provide shade for the livestock; they were calculated at the household level based on the survey information on livestock numbers and then extrapolated to account for the whole villages, as also shown in Table 31 in Annex C.

### 5.3.8. Impacts on income generation and the education level of children

**Impacts of prosopis on livelihoods.** No monetized value was calculated for the net benefits of prosopis for livelihoods or education at the sand edge of the villages. However, the shop keepers' income in the sand invasion areas was compared with that at more protected sites in the villages, and it suggested a reduced income for the former group. It was, however, impossible to conduct a relevant statistical analysis on this reduction, as the total number of shop keepers was small and the income level in Wad Killian, Al Figaiga, Dueimat and Tundub was not as high as in Al Hosh, even disregarding the economic burden caused by sand invasion. The people living at the unprotected sand edge had in any case become poorer due to the sand invasion and were not able to buy as much as the villagers not directly affected by sand invasion. Apart from the weeding expenses for tenant farmers and the tyre punctures affecting the drivers, there appeared to be few other negative effects of prosopis on livelihoods. These two impacts are presented in more detail in subchapter 5.3.13.

**Impact of prosopis on education.** The education expenses in the villages were progressive, as each household paid school fees in accordance with its capability. In Al Hosh, therefore, the wealthier households not affected by the sand invasion on the field side of the village paid higher school fees than did the poor, sand-affected households. The latter ones could send at least some of the children to school for a cheaper fee. For many, education was considered a sign of well-being, and, therefore, many parents wanted their children to have at least the primary education completed, even though the family really could not afford it. Another issue was that when most households were poor there was not much of a salary to be paid to a teacher. Thus the schools had problems in meeting their educational quality requirements. Both education and livelihood impacts would have needed a longer period of investigation to determine the long-term effects on the communities. Prosopis had anyhow almost exclusively positive effects on the education situation in the villages, as thorn injuries were almost negligible in the area.

### 5.3.9. Impacts in relation to land rehabilitation

**Description of environmental services and their impacts in the Gandato Scheme.** Prosopis provided *positive environmental services* in terms of soil rehabilitation and for the bufferzone area as a whole. Because of difficulties in monetizing the values of these environmental services within the scope of this study, only some indications on the magnitudes of these services will be provided. The land rehabilitation aspects of prosopis have also been covered in sub-chapter 2.2.3.

The carbon sequestration service is a potential source of income in the savanna areas of Sudan. In the financial year 2002 – 2003 there was, however, no real Clean Development Mechanism (CDM) project established in Sudan and even less so in the framed area of this study. The potentials have, however, already in the early 1990s been studied by the Global Environment Facility (GEF) and the United Nations Development Program (UNDP), which implemented the Community-Based Rangeland Rehabilitation for Carbon Sequestration and Biodiversity Project in North Kordofan State of Sudan. The final evaluation of that project concluded that the project strategy to rehabilitate and improve marginal lands had demonstrated a potential in enhancing carbon sequestration. The report further stated that the appeal of carbon sequestration in the semi-arid parts of Sudan lies in its large spatial dimension rather than in its intensity per unit of land area (CBD 2003).

Ardö and Olsson (2003) studied soil organic carbon (SOC) sequestration in an acacia savanna in the same area that was covered by the above-mentioned GEF/UNDP project. Based on results from the vicinity of El Obeid in North Kordofan State they concluded that the SOC sequestration capacity was annually approximately 0.75 t/km$^2$. Even though prosopis grew in the Gandato Scheme framed research area of the present study some five times faster than trees in the *Acacia senegal* savanna, the estimated amount of carbon sequestered would have been too small for consideration as a Clean Development Mechanism (CDM) funded carbon sequestration project (cf. Olsson and Ardö 2002).

The current prosopis bufferzone in the Gandato Scheme framed research area was only 10.75 km$^2$ in size (including the villages), and there were constant carbon leakages due to wood collection and free-grazing livestock in the area. Furthermore, only the actual shelterbelts had been artificially established and the rest of the prosopis buffer zone (comprising at least 80% of all prosopis in the area) was the result of natural regeneration and spreading of prosopis, which would not count as organized CDM activity. Prosopis trees were also unevenly distributed in patches in the whole buffer zone. The expenses for establishing proper plantations over the whole buffer zone area would be high, and such establishment would thus be unlikely to happen. Therefore, the small carbon sequestration benefits that could have accumulated in the prosopis buffer zone were omitted from the subsequent monetizing exercise.

In sub-chapter 2.2.3. it was stated that young prosopis trees tend to show a higher nitrogen-fixing ability than the already established older trees, and the amounts fixed were around 25 kg/ha of nitrogen for 650 one-year-old trees per hectare, which represents a fairly dense tree cover. In the Gandato Scheme the farmers used urea (50% N) as fertilizer, and a 50-kg sack of urea cost 5,000 SD. The prosopis trees in the framed area buffer zone were quite uneven in size and distribution, which means that their nitrogen-fixing ability could easily be over-estimated. The accrued benefits, when monetized, would in any case be fairly small.

**Soil analysis in the Gandato Scheme framed area.** Soil analyses were carried out for this present study. One year earlier a more thorough soil analysis for the planning of a commercial crop farm (the Maddiah farm) had also been conducted just some 3 - 4 km outside the framed research area towards the northeast, and the results of these two sets of soil analyses were used together.

The first set of soil samples for the present study was collected near Al Figaiga village from a 20-year-old prosopis shelterbelt stand bordering the irrigated agricultural fields. At each of four sample sites one sample was taken from the 0 – 25 cm depth and another from the 25 – 50 cm depth. A second set was collected from bare land some 7 – 15 m outside the 20 year-old prosopis shelterbelt stand at the bufferzone side of it, and a third set about 100 – 150 m from the shelterbelt inside an agricultural field from under 36-year-old mango trees.

Soil samples were analyzed by the Agricultural Research Corporation in Wad Medani. At the three contrasting sites the soil particle size composition was found to be different. As could be expected, the bare land showed mostly sand being present (coarse sand constituting 34% and fine sand 39%), while the prosopis stand had less coarse sand (14%) and more fine sand (49%). Of the remaining fractions silt was a little more represented than clay both in the bare land and in the prosopis stand soil. The mango stand soil inside the irrigated scheme had a low coarse sand content (10%), while fine sand, silt and clay amounted to 36%, 28% and 26%, respectively.

Another finding was that major differences which existed in the chemical soil composition were mostly confinded to the upper 0 – 25 cm layer. The organic carbon content of the soil did not vary much in the bare land and prosopis stand soils (0.21% and 0.25%, respectively), but it was higher in the mango stand (0.40%). The nitrogen level was almost five times higher under the prosopis stand than in the bare land soil (0.14% vs. 0.03%), while the mango stand also showed a low value of 0.06%. The phosphorus level was ten times higher under the prosopis stand than that in the bare land soil (45.0$\pm$ 23.2 mg/kg and 4.7$\pm$ 2.6 mg/kg, respectively), while the mango stand had a low value of 2.1$\pm$ 0.7 mg/kg. It was observed at the field site that the prosopis stand had a substantial amount of livestock droppings on the ground as well as a litter layer up to few centimetres thick, which most likely also affected the results (the actual litter layer was not included in the samples). Additional effects on soil properties caused by animals or the litter can conceivably be included as benefits of prosopis on the soil composition.

The Soil and Water Sciences Division (SWSD) of the College for Agricultural Sciences of the Sudan University of Technology had conducted the soil analyses for the new private irrigated crop production farm (named Maddiah Farm) in 2002 (Doka et al. 2003). The piece of land in question belonged to the bare soil area on the wind side of the Gandato Irrigation Scheme area. The SWSD laboratory results indicated a soil particle size distribution on the Maddiah Farm similar to that in the Gandato Scheme. The organic carbon content in the SWSD study ranged from 0.34 to 0.67%, and the nitrogen content from 0.003 to 0.08%, with averages somewhat higher for organic carbon and slightly lower for nitrogen than found in the bare land soil samples at the Al Figaiga site in the present study. No phosphorus analyses were conducted by the SWSD for the Maddiah farmland. An earlier soil analysis report by Buraymah (1975) classified the fields of the Gandato Irrigation Scheme as floodplain soils, while the framed prosopis buffer zone and the Maddiah farm land consisted of intermediate terrace soils, mostly of eroded sandstone and eroded ancient alluvial layers. According to Doka et al. (2003) the Maddiah farm land would be usable for crop production only with some kind of well irrigation and shelterbelts surrounding it.

### 5.3.10. Impacts on scenic values in the area

The Table 28 in Annex C presents the results of a landscape aesthetics survey in the Gandato Scheme villages of Al Hosh, Dueimat, Al Figaiga and Wad Killian. The household heads' opinions are given as normative values, which does not indicate how much people actually would be willing to pay (WTP) for either having or not having the prosopis in the framed area. There was no real need for any monetizing of the scenic values, as the results presented in Table 28 in Annex C indicate that, at the time of the survey, about half of the population was against and another half in favour of prosopis in the area. For the valuation point of view it can thus be concluded that a monetary value would in this case probably be fairly neglible. A zero value was therefore included into the benefit-cost analysis shown in Tables 31 and 32 in Annex C.

In some of the negative answers related to prosopis there were feelings which did not appear rational and which may also have been influenced by the official agricultural sector opinion that prosopis must be eradicated from the whole of Sudan. On the other hand, particularly in the shelterbelt-protected parts of Wad Killian, almost all villagers interviewed stated their opinion quietly, but one could tell that the answers were sincere. These people had in the 1980s and the early 1990s felt the situation without a prosopis shelterbelt in a heavy sand invasion frontline - a situation they did not want to be faced with again. It is thus difficult to tell what WTP bid each household would actually have made. The financial resources of the people living close to sand invasion were also more constrained than those of the tenant farmers and businessmen living in the more protected parts of the framed area. After the survey had been conducted in Al Figaiga, the Sudanese foresters who acted as hosts and interpreters discussed the prosopis protection situation with the villagers. It became apparent that the villagers had not fully realized what their life would be without the protection against sand invasion provided by prosopis. The discussion made them change their opinion, and the research team was warmly wished success in the further analysis of the prosopis situation in the area. Had this discussion taken place before the survey the results would probably have been different.

### 5.3.11. Impacts related to biodiversity

In the Gandato Scheme area of River Nile State the vegetation is typical for the arid and semi-arid regions of Sudan with a strong influence of the Nile. The river provides enough water to maintain a zone of fertile land maximally three kilometre wide on either side of the river with a rich indigenous flora but also highly suitable for agricultural practises. Further away from the Nile the native vegetation cover mainly consisted of *Acacia tortilis* var. *tortilis* and *A. tortilis* var. *raddiana*, *Merua crassifolia*, *A. seyal*, and *Capparis decidua*. During the last decades, however, the bufferzone between the fertile riverine zone and the railway, and even the land further away from the river along the highway, had become mainly occupied by prosopis or consisted of bare sandy openings. The ground flora had earlier been dominated by *Panicum turgidum*, *Aristida mutabilis* and *Cymbopogon nervatus*, but it was now very sparse (cf. Buraymah 1975; ElRahman 1991; Doka et al. 2003; ElHassan 2004).

The Nile is part of one of the world's most important bird migration routes between Europe and Africa used by millions of birds every year. This eastern African migration route is one of the best places to cross the vast Saharan desert for all kinds of migrating birds which stay in the tropics during the cold European winter months (Mockrin and Thieme 2001). It is known by bird migration researchers who have fastened satellite radio transmitters, for instance, on Finnish ospreys or on Danube delta-born great white pelicans, that these birds often migrate between Europe and the wetlands in southern Sudan and Niger passing on their way in both directions the Nile banks in the Shendi area (cf. Saurola and Björklund 2002 and 2004; Izhaki et al. 2002). Sudan is supposed to harbour some 900 species of resident or migratory birds. There are also various kinds of mammals such as a small deer (duiker), the desert fox (fennec), the rabbit, and numerous small rodents and bats resident in the riverine zone of the northern states of Sudan (Bashir 2001).

Table 29 in Annex C lists the bird group names for species observed by the researcher in the riverine area in Shendi during three weeks in January 2004. The birds are listed by genus or group name only as it was safer to correctly identify these than the individual names of species. For the identification of these birds and their respective scientific, English and Swedish names the following references were consulted: Heinzel et al. (1972); Det Bästa (2005); and Birds of Britain (2006).

Adjacent sites where the riverine vegetation had been destroyed by sand dune and sheet sand invasion suggested that the biodiversity in these types of ecosystems would have been reduced. A large number of migrating birds would not find suitable habitats there and would therefore continue their path to more fertile areas further south after flying along the Nile through the Sahara desert. Also mammals and reptiles would show a reduction in abundance, but these animal groups are better adapted to the desert fringe areas than the migrating birds.

Table 30 in Annex C presents a list of tree species identified by their scientific names around a tree seedling nursery operated by the Forests National Corporation in Shendi and located in Al Glea village area about half way between the framed research areas in Gandato and Shendi. Most of the tree species would not be able to grow in the riverine area in Shendi without the currently prevailing protected riverine micro-climatic conditions.

### 5.3.12. Protection of potential historical and archaeological sites

The Shendi area is highly interesting from the archaeological and historical point of view. The old kingdom of Meroë had its capital just some 35 km to the north at the Nile at what is now Bagrawiya village. Today both the old city of Meroë and an area with numerous small pyramids can be visited by tourists. Between 1976 and 1983 a French archaeological research unit of the Directorate General of Antiquities and National Museums of France carried out 14 excavation missions to the Shendi area. Most of the investigated archaeological sites were between Shendi and the Taragma pump station some 15 km to the northeast along the Nile. Sites such as El Kadada, El Ghaba, El Hatra, El Ushara and Shaqalu have revealed rich prehistoric and historic burial artefacts radiocarbon-dated to the Neolithic period (from the fifth and fourth millenniums B.C.), the Napatan period (eight to fourth centuries B.C.), the Meroitic period (fourth century B.C. to fourth century A.D.) and the post-Meroitic period (fourth to sixth centuries A.D.). The Meroë town had its own iron manufacturing industry. Some 50 – 100 km southwest and south of Shendi there are several well-known temple ruin areas mainly from the Meroë period, such as Wad Ben Naga, Musawwarat es Sufra, Naqa and Shaqadud. The sixth cataract of the Nile lies about 100 km south of Shendi (Geus 1984).

In El Kadada some burial sites appear older than the surrounding Neolithic layer, but they are undated. A large archaeological (mainly Neolithic) site occupies an old river terrace, southwest of Shendi, near the edge of the Gandato Irrigation Scheme; this site has to some extent been destroyed by later settlements and modern scheme constructions. On the western side of the Nile opposite to Shendi there are some 20,000 – 30,000 ancient burial sites identified along a 50-km strip of the riverine area between El Salluab and El Heleila, some 25 km southwest and 25 km northeast of Shendi, respectively (Geus 1984).

While conducting the household surveys in the framed area it was observed that both Al Figaiga village and Dueimat village lie on small, approximately ten-metre high hills. The closest rock outcrop can be seen in the southern suburbs of Shendi some 16 km away, and as the village hills appeared to consist of more compacted material than just sand dunes, it is possible that the hills could be man-made. The current villages could have been built on the ruins of older villages or even those of ancient towns; or alternatively, the Al Figaiga and Dueimat villages could be old by themselves and debris from older buildings could form the hills. These observations and hypotheses would need some basic archaeological investigations for supporting evidence. Archaeologists have already found many ancient sites under hills along the Nile in River Nile and Northern States, whereby a possibility that something of value could be found does exist. For instance, archaeologists have recently found, some 200 km further north from Shendi, a large temple town at Dangeil close to Berber town which dates from the Meroitic period (Yakutchik 2006). Many smaller sites are probably still unexcavated in the area. Whatever would be found at the Gandato Scheme site could not be monetized for the present study, but the prosopis bufferzone anyhow protected the area from being covered by drifting sand.

### 5.3.13. Main detrimental impacts of prosopis in the framed area

The costs of the negative impacts of prosopis were estimated and calculated at market value as explained earlier in the methodology chapter. These results are presented in Table 31 in Annex C. The Forests National Corporation (FNC) office of River Nile Province in Ed Damer had in 2005 weeded the main canal of the Zeidab Agricultural Irrigation Scheme and could provide concrete cost figures. The cleaning of the main canal had taken 80 machine hours per kilometre and cost 1,200,000 SD/km. The cleaning had to be done every second year, according to the head of the FNC office in Ed Damer.

The costs related to prosopis presented in Table 31 in Annex C cover, apart from the main canal cleaning, also the weeding in the fields and the various vehicle tyre punctures for the whole framed area in Gandato Scheme, for which the calculation approach has been described in sub-chapters 4.4.13. and 5.2.

### 5.4.14. Presentation of the scenarios for the TEV study

Table 31 in Annex C contains a compilation of all TEV analysis results for two different scenarios as outlined in the methodology and results chapters and provides the material for the synthesis shown in Table 31 in Annex C. Scenario A, or the current reality situation, assumes the prosopis bufferzone covering about half of the framed area outside the irrigation scheme. In Scenario B prosopis is hypothetically assumed as absent from the framed area. The current impact of prosopis in the framed area in the Gandato Scheme is then the difference between Scenarios A and B as outlined on page 37 in the presentation of Pierce's equation. As indicated in Table 32 in Annex C, the monetized benefits derived from prosopis exceeded the costs in this total economic valuation (TEV) analysis by a factor of 46. On top of this value there were still all the positive values, presented in sub-chapters 5.3.2. to 5.3.14., which were not monetized in the present study. The free-grazing forage, environmental conservation values and wood energy, as well as various shelterbelt effects, formed the major parts of these benefits.

With the establishment of a shelterbelt of prosopis for the framed area over the whole bufferzone against sand invasion from the northeast, the benefits (for the same environmental services as monetized above) could still be increased to total some 50 times the value of the social costs, as shown for Scenario C in Table 32 in Annex C. Scenario C was calculated almost directly based on the values from Scenarios A and B; only the estimations for the costs of car tyre punctures caused by prosopis thorns needed some further separate calculations. This was done based on the current situation in each respective village and then cross-examined using, for the currently unprotected villages, scaled estimates obtained from the protected villages. If the current type of prosopis could have been kept out of the irrigation scheme by planting new shelterbelts against the fields with a thornless prosopis variety or another tree species and if no livestock had been kept in the fields, then the Scenario C benefit-cost ratio would probably have increased further.

# 6. DISCUSSION

## 6.1. Outline of the discussion

The present discussion will first synthesize the household economy results from the New Halfa and Gandato Irrigation Schemes, as well as the overall magnitudes of impacts from prosopis in the New Halfa Scheme. The results from the TEV analysis for the Gandato Irrigation Scheme are thereafter discussed in the light of the valuation approaches used. A third smaller set of results comprising the linkages of malaria incidences with trees in irrigation schemes is then discussed. The discussion ends with a holistic synthesis of prosopis and its environmental management in the context of Sudan, and presents some recommendations and conclusions for the sites now studied. - Figures 15 - 24 in Annex C illustrate in photographic form various situations where prosopis affects people's livelihoods.

## 6.2. Overall synthesis of the livelihood situation in the New Halfa and Gandato Schemes

Probably due to the fact that most of the household heads interviewed were poor and their respective situations were well known already to their neighbours, there were only a few persons who did not sufficiently disclose information on their income. The persons interviewed were usually not paying income tax apart from standard taxes on crop cultivation, livestock management or businesses. Therefore the respondents were not afraid of a researcher's questions possibly hurting them economically. It is likely that such sensitive household data could not as easily be collected in a more developed country with a higher income taxation rate. For comparison it could be mentioned that in an ethnic minority culture context in western Sichuan Province in China, the researcher has used the same household economy calculation approach (Laxén et al. 2007) with some adjustments for the totally different cultural and ecozone setting, without any problems.

It is currently not easy to find sites where there would be areas under exactly similar conditions covered by prosopis and those completely devoid of prosopis. The northern parts of the New Halfa Scheme had almost no prosopis and could in principle have formed such a comparative area, although some 50 km apart from the selected framed area. The selected approach to hypothetically omit prosopis from the framed research area as desk study work appeared the most convenient way of achieving the comparative scenarios for analyzing.

Tables 1-12, and 19-21 contain, for each cash income quintile, the mean incomes and standard deviations for these means for all the studied population groups in the New Halfa and Gandato Schemes. The large differences and absolute values in standard deviations should be interpreted as diversity among households in income source and size. This is normal in any village, but villages with more diversified income generation obviously show larger differences.

For the population groups in the New Halfa Scheme area in Sudan one can distinguish all the four predominant pathways out of rural poverty categorized by Wunder (2001) on the basis of poverty-reduction studies from various tropical and sub-tropical regions:
(a) The multiple-activity path (rural diversification into non-farm activities);
(b) The rural-urban migration path (labour movement and reallocation);
(c) The agricultural path (the traditional rural development model); and
(d) The assistance path (aid, transfers and public investments etc.).

In the framed area of the New Halfa Irrigation Scheme, category (a) was represented by non-farm livelihood diversification into prosopis utilization (as charcoal, fuelwood, poles and fodder). The category (b) type of labour migration was mainly identified in some male or female family members who had left the scheme for a city and sent cash money back to the families. Category (c) was the main one for the tenants, but many of the various kinds of landless households also used this strategy as their first income generation option, in combination with some of the three other poverty alleviation pathways. The category (d) pathway was used by many of the households in the form of private cash transfers from relatives or by trying to get a share in the irrigated crop production opportunities that the publicly financed irrigation scheme had established and upheld in the area.

The population in the framed area of the Gandato Irrigation Scheme was more closely linked to the opportunities that the cities of Shendi and particularly Khartoum were able to provide than that of the New Halfa Scheme. The poverty reduction pathways defined by Wunder (2001) and described above were also found in the Gandato Scheme framed area. The category (a) pathway was in Gandato mainly used through the prosopis forage opportunities for livestock which otherwise could not have been sustained at such a high level. Households that collected prosopis fuelwood did it mostly for their own subsistence use, although some unidentified households also traded in fuelwood. Pathway (b) was also frequently found in the Gandato framed area. Many males worked in cities and came home to the villages for the night, or a few times per month, if they worked in Khartoum. The category (c) pathway of agricultural activities was, of course, the predominant one, although many households in all the framed area villages did not have access to the irrigation scheme. The category (d) pathway based on private cash transfers also existed, although it was more closely connected to the (b) pathway, due to good commuting opportunities to Shendi and Khartoum.

Results from the New Halfa Scheme case show that the major beneficial impacts from prosopis in this framed area could be grouped into three main categories: (a) free-grazing forage; (b) wood energy; and (c) other wood and NWFP utilization. On the detrimental effect side there were also three categories: (d) costs accruing to agriculture and scheme canal maintenance and weeding; (e) punctures on vehicle tyres; and (e) detrimental health impacts. Apart from these presented categories which could be analyzed, there were also some other potential impacts that were difficult to valuate credibly. These were mainly related to biodiversity and land rehabilitation.

In situations where the economic agricultural productivity potential was low there were non-farm income opportunities provided by prosopis that were attractive to the poor, especially in regard to its safety net functions. In particular, all three landless population groups in New Halfa used prosopis for such functions. The safety net functions were, however, under constant pressure, as the above-mentioned groups were politically weak and powerless and their opinion did not count much against that of the scheme management or the state or national authorities, as far as the forest resources were concerned. The poor households therefore maintained a more diversified livelihood strategy, so as to reduce the risk of failure in one livelihood source, but partly also because they needed a sufficient income which one source alone could not provide. According to Angelsen et al. (2005), it is important to distinguish between the use of forest resources only to prevent people from falling deeper into poverty, and, on the other hand, giving these resources a role in lifting the households out of poverty on a more permanent basis. Further, according to Ellis (2000), such a diversification of a poor household’s livelihoods tends to offset part of the pressure on environmental resources.

To earn an income from prosopis wood extraction is hard work and best suited for the younger males in good physical condition (cf. also Fisher 2004). The prosopis weeding, cutting and charcoal-making in the New Halfa Irrigation Scheme was no exception. The use of unprocessed wood and non-wood forest products (NWFP) resources gave in most instances only a low income per production unit. However, the prosopis-invaded agricultural fields in the New Halfa Irrigation Scheme had a high land-use value once cleared from prosopis, and this spilled to some extent over to the weeding and cutting unity prices received in New Halfa. Therefore, in these circumstances, prosopis weeding and cutting could be better categorized as at least medium-income forest activities.

NWFPs often serve subsistence needs, fill an important safety net function, or even provide regular cash income. However, as most NWFPs are open for public access and labour-intensive and have low investment and skills requirements, they often provide poor prospects for market and price growth (cf. Angelsen and Wunder 2003). The prosopis charcoal in New Halfa had in the years 2002 - 2004, however, a substantial market and even a small price growth potential outside the framed area. The use of bottled liquid gas was spreading in the area and taking over part of the energy market since it became available in 2000 (cf. Salih 2000). Many of the tenant households stated that they partly used liquid gas instead of the prosopis-based wood energy, which was seen as inferior for these households. Particularly in the northern parts of the New Halfa Scheme and in the Gandato Scheme the price of bottled gas was therefore setting a price ceiling for the prosopis charcoal sack that also included its transportation costs. The commercial trading (including reselling and transportation) in prosopis charcoal outside the framed area was, during the data collection period, was already mostly in the hands of outsiders or the local Nubian tenants, while the hard work of charcoal making and petty selling was in the hands of the landless population.

Angelsen and Wunder (2003) categorize the importance of NWFPs into three strategies based on the proportion of the total income derived from NWFPs, which adapted to the New Halfa context could be described in the following manner:

- <u>Specialized strategies:</u> Forest products provide a large share of the total household income and a large share of the total household cash income. At the New Halfa site the specialized charcoal-making belonged to this group for some households.
- <u>Diversified strategies:</u> Forest products occupy a small share of the household income, but have a high market integration. At the New Halfa site, for many households, the prosopis weeding and fuelwood and pole cutting belonged to this group.
- <u>Coping strategies:</u> Forest products have a small share of the household income and a low market integration. At the New Halfa site such forest products included, for instance, the subsistence fuelwood when selling of fuelwood played a smaller role in the household economy.

The present study tackled and distinguished in New Halfa and Gandato also such issues as social heterogeneity and social differentiation, which should be analyzed when more complex sociological and ecological settings are to be understood and policies need to be prepared and enforced. Omitting the forest environmental (prosopis) incomes from rural household economic statistics would lead to underestimation of the total annual incomes. This in turn would cause an overestimation of the number of rural poor, if such an estimate is only based on the household cash income levels. Important forest environmental cash and subsistence income sources need also to be included in national poverty reduction strategy papers, concentrating especially on the basic needs, such as food, fuel, fodder and protection (cf. UNCCD 2004; Vedeld et al. 2004).

It appears, by coincidence, that the current President of the Democratic Republic of Sudan was born in the Al Hosh village of the Gandato Irrigation Scheme before moving away for a career in Khartoum. Now a presidential decree is indirectly causing increasing poverty among the population in Al Hosh and all other similar River Nile and Northern State villages which are left unprotected against sand invasion and do not have the choice of planting prosopis. During the last decade many families have left Al Hosh due to sand invasion, and many more are considering leaving the village; several of these have already started the preparations to leave Al Hosh. A prosopis shelterbelt on the windward side of the village would at least partly curb this current trend. These leavers seek a better life in Khartoum or Shendi, and the resettling will not stop completely, but without sand invasion of their houses the leavers would be fewer and those who actually leave would get money from selling their house property and irrigated fields, which they rarely do if the sand has taken over the houses and yards.

In many standard scientific household surveys, the forest environmental income share is consistently underestimated and the agricultural income thereby overestimated. This kind of over-estimation is also something that the local population in the two framed research areas do themselves as well. It appears that crop production has the largest operational turnover of cash during one cropping season, but the gross margin income is not higher than that from other income sources in most household cases. The lack of cash is a major problem facing the poor in the community, and the major source of cash income is from non-farm activities, such as prosopis charcoal-making, business, labour work, town jobs, and private cash remittances from relatives. Poorer households also engage themselves and invest in crop production activities similarly to the wealthier households, but the return on their investments is often lower than what the wealthier ones can get. The best option for the poor households is thus to maintain a diversification of income, as many small income sources together may constitute a sufficient livelihood.

The possibilities to significantly reduce the overall poverty in the New Halfa and Gandato Schemes involve high costs, although there are some cheaper options that could be explored to alleviate the poverty. In the New Halfa Scheme the first priority is that water be stored in the Khasm-al-Girba dam instead of the irrigation canals; this would reduce the vegetation in the canals and eliminate many breeding places for vectors of diseases such as malaria. Further, prosopis cannot be eradicated without proper plans for substituting the tree with other tree resources in the framed scheme area. While prosopis regenerates vigorously by itself, it is highly likely that a replacing tree species would not perform as well. New tree nurseries, annual outplanting and silvicultural tending would require funding and labour of which the latter could preferably be recruited among the landless population. Another priority option would be the improvement of road connections in the scheme, whereby some remoter villages could be more easily reached during the rainy season; this would also better stabilize their village micro-economies and link them closer to larger economies.

In the Gandato Scheme framed area the priority poverty-reducing improvement seems to be the establishment of functioning shelterbelts against sand invasion in the affected villages and agricultural fields, which will considerably improve the livelihood situation for many households. At the same time, also the Hassania households of Al Hosh and the 30 unprotected households in Wad Killian should be supported so that they could move into the bufferzone area which would be protected by the new shelterbelts. An expanded bufferzone of prosopis would also increase the availability of free-grazing forage in the area. An additional main improvement relates to the expansion of the road infrastructure, which would reduce the distances between the villages in Gandato and the markets, and thereby raise the crop selling prices and create new off-farm livelihood opportunities through better commuting to cities for the pursuit of jobs there.

### 6.3. Discussion on the TEV and the magnitude-of-impact studies

The present study included one TEV analysis for the Gandato Scheme and a study on the magnitude of the scale of impact for the New Halfa Scheme. It is important to assess site-specifically both the benefits and the social costs and to derive the right magnitude of impacts for each area. Also the monetizing of the quantified benefits and social costs must be done specifically for each area. Often the researchers and managers who conduct TEV studies have higher ambitions. They therefore make short-cuts due to the time and effort constraints as well as outside demands, so as to conduct the study on a scale which national decision-makers find useful. A careful balance between the quality of results and the actual needs of decision-makers must therefore be made from the start.

The present TEV study has been calculated from a local community valuation angle, where local prices and perceptions have determined the economic results. Wide-spread recognition of some limitations concerning conventional TEV studies have during the last decade resulted in studies with an actively encouraged involvement of the local communities and local authorities in the economic valuation of their environmental reosurces. Such an approach is called Participatory Economic Valuation (PEV), and it has to date been practised only in a few cases in developing countries. A case study carried out with this approach was, for instance, a forest valuation exercise from Vietnam (Kuchelmeister 2003). The PEV approach is still evolving and slowly becoming better known in wider circles. The present TEV study could, perhaps, be seen as a compromise between a conventional TEV and a PEV. Especially for studying an invasive alien tree species causing conflicting attitudes among people the selected present approach seems to be useful.

The TEV study from the Gandato Scheme and the magnitude of the impact study from the New Halfa cannot be directly generalized for other parts of Sudan as the site selection was done subjectively. However, with some further field assessment at such other sites one could determine which impacts are prevalent at a particular site and thereby make rough estimates on the monetized impacts of prosopis for that area based on results of the present study. Further, the present study can also provide models for how the monetization work could be done for other sites and thereby enable a fast and efficient data collection and analysis when one knows what impacts to look for. The selection criteria of the two research sites considered, for instance, the below factors in relation to prosopis:

- Clay soils versus sandy soils;
- An arid versus a semi-arid ecozone;
- Sand-invaded villages versus villages protected by prosopis;
- A variety of impacts from prosopis;
- A site logistically sufficiently easy to reach and study;
- Including a site commonly anticipated as showing the most negative prosopis effects in Sudan;
- Including a site from northern Sudan where prosopis does not have many substitutes;
- Sites inside major agricultural areas where most of the criticism towards the tree has originated;
- A sufficient number of people living in a selected framed area;
- A local population with diversified income generation and differences in income distribution.

The TEV analysis results from Gandato can be considered almost free from overlapping of benefits and costs, particularly due to two reasons. The first reason concerns the selected valuation techniques that mostly belong to the revealed preference approach group. Such values are mainly analyzed and monetized at their direct use values, even if the cost avoidance and the mitigation of cost valuation techniques also cover intangible and intrinsic values. The second reason derives from the fact that some of the most difficult-to-monetize environmental services were actually not valued but left at a descriptive level, when it could be seen that these services could be defined as positive impacts. To these services belonged, for instance, the valuation of land and soil rehabilitation, the protection of biodiversity, archaeological and historical assets, as well as the amenities, which all are likely to be traps of overlapping values. An exception to this rule were the health impacts of prosopis, which covered both positive impacts (e.g. reduced incidences of respiratory diseases and stresses caused by the climate and sand invasion, etc.) and negative impacts (thorn injuries to humans and animals, as well as some part of the increase in vector-borne diseases such as malaria).

The focus of the household surveys was on those villages in the framed area in the Gandato Scheme which were either protected or not protected by prosopis. This led to a near complete omitting of the Tundub village from the household survey, as this village was representing a compromise between the contrasting issues studied in the other villages. This did not matter in the household survey part of the present study, but if this kind of a survey is to be repeated in the future, all framed area villages should preferably be included. Now the approach for how the household economic information was used in the TEV study was developed after the field visits, and the Tundub information was found lacking. It saved time and effort when this missing data could be replaced by profiling of the households with proxy data from the other villages in the framed area.

For the monetized public goods, externality and other impacts, a one-year financial analysis formed a TEV study and indicated that, for the situation in the financial year June 2002 to June 2003, the total benefits including the externality benefits outweighed the total costs, including the externality costs, by a factor of 46. Had the whole framed area had a buffer zone of prosopis, the externality benefits would have outweighed the externality costs by a factor of 50 when calculated for the same impacts. These are average figures, and for many households the benefits were crucial for survival. On top of this, for Scenarios A and C, all the non-monetized positive impacts listed above should be added. Without a functioning riverine ecosystem and agricultural crop production in the area, the attraction to live in River Nile and Northern States of Sudan would be significantly lower. There is already a substantial percentage of the population in these two states which is leaving the region for a better life in the Khartoum area or elsewhere in Sudan.

Sub-chapter 3.2. elaborated on the validity of the results and on how much of the intangible externality values would eventually be included without the stated preference valuation approaches. Due to the fact that the present study was conducted as a TEV analysis it can be estimated that a substantial part of these above-mentioned public good and externality values were included in one way or another. In fact, the approach adopted in this present study to keep some of the valuation exercises fairly concrete is potentially a good general option, as the risk of overlapping of the intangible externality values thus becomes smaller. In case only one externality would have been sought for, then a stated-preference approach may eventually have proven itself more useful and could also have been used as an optional valuation approach for comparison.

In the present study, whenever local financial market prices were available these were used. According to Boxall and Beckley (2002), surpluses on market prices also exist in developing countries, but these surpluses are usually bartered rather than sold in exchange for cash. Therefore the use of stated preference valuation methods is even more challenging in developing than in developed countries. Other researchers (cf. Campbell and Luckert 2002; Cavendish 2002) have also concluded that the local market prices for most NWFPs can usually be found at each site, and despite questions regarding their efficiency, these researchers have considered it better to rely on such market prices as proxies. Most alternative approaches to price calculation, such as modelling for determining the efficiency or shadow prices, would only be overly complicated and seldom even justifiable. An optional valuation sometimes employed for NWFPs is the opportunity cost of labour (cf. Bishop 1999). The opportunity cost for the time spent on harvesting NWFPs at the prevailing labour wage rate is taken as the proxy for the value of the product in question. However, this kind of an approach has commonly been discarded, due to problems encountered with this technique particularly in developing countries. In the present study where the aim was primarily to identify the magnitude of impacts rather than the absolute prices for environmental goods and services, the local financial market prices worked at least satisfactorily.

The preventive expenditure, or mitigation of cost, approach is a valuation method for goods and services consisting of estimating the costs of preventing a reduction or mitigating an increase in some impact. This valuation approach is able to incorporate also some intrinsic values (Bishop 1999). In the present TEV study, the method was used to valuate the conservation of the native forest vegetation made possible by the availability of prosopis resources which could grow faster than needed for the local wood and fodder consumption. Further, it was used in combination with other valuation approaches as part of the valuation of the non-market livestock fodder price. Especially in developing countries, where the social environmental awareness is usually fairly low among the rural people, it is important to try to catch the intrinsic values in indirect ways. The two cases in the present TEV study where this approach was used were related, as they both formed part of the fully monetized value of the prosopis bufferzone stand in combination with some of the other analyses conducted.

Regarding the selection of the livestock fodder valuation method as part of the household economy study, other researchers have used related techniques. Cavendish (2002a) valuated the “grazing services” by assuming 70% of the feed coming from outside agricultural fields or from crop residues, and he proceeded to valuate the livestock by examining the prices of animals and converting them into a stream of benefits over time. Campbell et al. (2002) used data on actual livestock production functions (milk, draught etc.) and used these to calculate the livestock income. However, the latter researchers refrained from estimating the amount of livestock feed derived from crop residues, as this was taken *in situ* on the fields, and further from giving crop residues a price, as these were not sold on any markets at their research sites. The present study, however, also incorporated such fodder values and amounts by using scientifically backed estimates based on research conducted by Abdelgaabar (1986 a,b) and others quoted in the text in connection with the field observations.

The use of the production function approach is an attempt to estimate the impacts on economic production or consumption losses (Bishop 1999). In the present TEV analysis this approach was used to estimate the impact of shelterbelts on the micro-climate for crop production. There is a risk that this approach becomes too theoretical when the actual situation in the field is not easily monitored, as shown in the present study. An attempt to counterbalance this was the use of average crop selling prices and the use of scheme statistics for the whole villages under study to scale the impact for each crop satisfactorily. The results obtained in this TEV externality analysis mainly indicated the possible magnitude of the impact, but due to many conflicting impacts (for instance, on crop prices) there is a high risk of misusing this method. In the present TEV externality analysis a single crop selling price was used for each crop type. This to some extent probably clarified the difference between unprotected and protected land for the local households and authorities which are too close to the situation in the field to perceive its complexity. This approach was also able to reduce the impact described by Campbell et al. (2002), who concluded that richer households withhold farm products until better prices can be obtained, as they have better access to market information and more cash and other resources to avoid crisis sales into which the poor households may be forced.

The replacement cost or the cost avoided approach is a valuation method often misused when valuating services derived from forests; this has somewhat eroded the credibility of this approach (Kengen 1997; Bishop 1999). Therefore, this approach was used for the TEV analysis only in fairly clear cases, while carefully refraining from using it, for instance, for estimating the values of soil improvement, land rehabilitation or the biodiversity, which all are complex services and often intertwined with other environmental values. It is also a normal practice to limit the valuation to a least-cost option, or anyway to a realistic scenario, in order to avoid over-estimation.

The method used for valuating the accommodation quality was considered belonging to the cost avoidance approach. The rigid housing prices in the Gandato Scheme would also have allowed another optional valuation approach with a kind of a hedonic pricing method. A hedonic price refers to a price which provides to a person a good or service that fulfils a level of pleasure for that person. Hedonic pricing is therefore a method used for valuating such goods and services (presented as characteristics) that directly affect the market prices of some other linked goods or services. A base assumption of the method is thus that the price of a marketed good is determined by its characteristics, or by the services it provides. For instance, the price of a house is seen as a reflection of the characteristics of that house – size, comfort, location, sand invasion, dust in the air etc. This optional method could for the present study have been used in a turn-around manner as compared to the way it is normally conducted, as the prevalent rigid pricing of house property in Gandato enables the valuator to estimate the desired accommodation quality (e.g. a two-room house with veranda) at a rigidly set price level.

The basic assumption would then have been that all houses in the villages had in principle the same basic price per room, as did the house location within the villages. Additionally, there were not many, if any, houses that had been sold within the villages. In Shendi town there was some price differentiation for housing property to be seen developing during the previous years, but this kind of pricing pattern had not yet in practice started to expand to the surrounding villages. The choice for a house site appeared more to be between the village and the urban setting of Shendi or Khartoum than between the within-village alternatives. This study would then not have been able to analyze more in-depth people's own awareness of the environment and the landscape aesthetics at their choice of house site – rather, it would have used for differentiation the physically forced impacts of sand invasion with which the households had to comply in order to survive. The monetized value obtained with this method would have been almost equal to that now received using a cost avoidance approach.

According to Boxall and Beckley (2002), the hedonic pricing valuation approach is rarely used in developing countries, due to lack of information on property prices and market goods, in combination with a further lack of relevant information on the households' environmental preferences. The same researchers also stated that there could be cases where this valuation method could potentially be used in developing countries and mentioned as an example the hotel room rates in Zimbabwe which fluctuated by a factor of up to ten for the same type of rooms. Bishop (1999) found no examples of using hedonic pricing in developing countries.

Earlier it was already concluded that the 70 households studied in the Gandato Scheme survey used, on average, 471 bundles of fuelwood during a year (see sub-chapter 5.2.3.). This would equal an average annual amount of fuelwood collected in the framed area of 854 kg per household. Further it appears that the consumption of fuelwood was on the decline in the area, as indicated by some earlier estimates on the amount of fuelwood consumed per household:

- In a study conducted in the the Zeidab Scheme about 100 km north of Shendi in 1989, an average family used 2,354 kg of fuelwood annually (ElRahman, 1991).
- In 2003 the households on the Matemma side of the river in Abdutab, Salama, and Seyal Kabir villages used, on average, 1,688 kg fuelwood per year. Apart from the fuelwood, 52% of the respondents also used liquid gas for cooking and some other energy sources (ElHassan, 2004).

The population on the western or Matemma side of the Nile is poorer, with fewer domestic energy options available in comparison with the households of the Gandato Scheme villages, which would partly explain the differences in fuelwood consumption between the two sides of the river. The difference between the findings by ElRahman (1991) and the results of the present study can perhaps also be to some extent accounted to differences in the size or composition of households.

The framed area totally included 1,390 households. In case the prosopis-related monetized beneficial and detrimental impacts were evenly divided over all households, the average annual household beneficial impacts would be 607,000 SD and the corresponding average annual household social costs would be 13,500 SD. Desertification is threatening the White Nile and the main Nile River almost similarly from Kosti some 300 km south of Khartoum up to north of Dongola in Northern State. Along the whole of this stretch of the Nile, totalling over 1,000 km on each side of the river, there are sand dunes and sheet sand invading villages not protected by prosopis. On the other hand, the native tree species there are unable to protect the villages from the invading sand, as large sand dunes are able to move through the riverine native acacia stands as sheet sand and even cross the river. Therefore, it is possible, with the present results, to estimate the beneficial and negative impacts simply by estimating how many households live in the frontline of the invading sand along the Nile River system. After all, this is the life-line of Sudan with an average human population density of 370 persons per $km^2$.

Carbon sequestration is considered as an important environmental service on forest lands. However, land use, land-use change and forestry (LULUCF) carbon sequestration projects implemented during the last years in the USA have usually each sequestered some 100,000 tonnes of carbon a year (Olsson and Ardö 2002). A preferable LULUCF project should be considerably larger than the 10 – 50 tonnes of carbon per year estimated for the framed area of the Gandato Irrigation Scheme to be able to attract any kind of interest from the industry in a developed country, even if small-scale carbon sequestration through afforestation activities has lately also been considered (cf. Chomitz, 2000; Garcia Quijano et al. 2004; Schlamadinger et al. 2004; Verchot, 2004). Forest plantations included in such a CDM project must also be planted primarily for the CDM project and not for other purposes (Olsson et al. 2001; Brown 2002; Schwarze et al. 2002; Porporato et al. 2003).

Katila and Puustjärvi (2004) concluded that, by the end of 2003, proper markets for environmental services rarely exist for other forest products than those that are directly consumable. Some cases which earlier were seen as good examples for environmental services, such as, for instance, the Environmental Service Program in Costa Rica, are struggling with sustainability problems in the absence of state support. Furthermore, the same authors concluded that, in 2003, the potential to increase carbon sequestration through afforestation or reforestation under the Clean Development Mechanism (CDM) was exceeding the demand for such activities.

### 6.4. The link between malaria and trees in irrigation schemes

The unchecked vegetation cover, of which prosopis constitutes a major part, increased the incidence of malaria, but the problem would most likely prevail in New Halfa or any other similar site in the tropics also with any other kind of poor water management and a vegetation cover suitable for the disease vector mosquito. In contrast, the present study did not find any particular indication that trees would impact on the incidence of schistosomiasis in the irrigation schemes studied.

Studies from the large Gezira Irrigation Scheme along the Blue Nile (WHO 1985; Oomen et al. 1994) some 200 km west of the New Halfa Scheme have indicated that malaria has been closely linked to the agricultural development in the scheme since it was initiated in 1924 and a continuous disease monitoring has been needed. By the early 1970s, the local disease vector mosquito, *Anopheles arabiensis*, had developed high resistance to the pesticides spread in the scheme and a major health crisis threatened the scheme population. The main breeding grounds for the mosquito were found to be the small "abu eshreen" feeder canals, irrigation ditches, drains, swamps, and lands that were flooded due to excess irrigation water. This main insect vector in Gezira preferred clear, stagnant water with little shade or with low vegetation, such as grasses and aquatic weeds. The initiation of wheat cultivation during the winter months was a further critical element in the increase of malaria transmission, as it meant cultivation during a period which previously had been idle in the scheme. The irrigation flow in the scheme during the winter months almost doubled, and this was the time of the year when the air temperatures favoured a long life of the adult insects. The mosquitos were therefore better able to pass the *falciparium* malaria to new human carriers.

WHO-supported studies have elsewhere in the tropics suggested that an increase in hazards for water-borne diseases is largely related to the following circumstances (Birley 1991; Tiffen 1991):

- Soils present drainage problems, and drainage channels are absent or not well maintained;
- Rice or sugar cane is cultivated;
- Reservoirs are constructed or various types of pits are left with stagnant water;
- Canals are unlined or have unchecked vegetation growth; and
- An irrigation scheme has received new immigrants or includes compact resettlements with poor living conditions; this brings into the scheme new diseases or favours diseases that have a good breeding ground in the scheme area.

Outside the irrigation schemes, the most suitable mosquito breeding places have included wells, water storage tanks, broken water pipes, open water channels, pits and depressions inundated by flood water, drainage channel storm drains, and even various small vessels filled with stagnant water (Onwujekwe 2002). The temperature determines the survival rates of both the vector and the parasite, while precipitation and irrigation determine the number of breeding sites. High temperature shortens the aquatic cycle of the mosquito from perhaps 20 to only 7 days and reduces the time of emergence and oviposition. It is assumed that the maximum tolerable temperature for the malaria mosquito is 32$^{o}$C, above which temperature the mosquito will die. During the midday sun hours the mosquitoes are therefore in hiding inside houses or tree crowns or in similar places (Listorti and Doumani, 2001). A climate change towards a hotter climate would alter the current situation, to the extent that, for instance, the winter months would become more malaria-prone than before (MEPH/HCENR 2003; Teklehaimanot 2003).

The results of the present study regarding the malaria incidence in the New Halfa and Gandato Irrigation Schemes are mainly indicative, as the household surveys now used in the villages should be followed up by relevant laboratory tests and larger, focused field surveys, so as to confirm the cases of malaria and to clearly distinguish it from other diseases. However, when people wrongly assume that they or their children have contracted malaria, their reactions and in most cases also their costs for curing the disease are the same as when it actually is the case (cf. Sachs and Malaney 2002). It is worthwhile both in the short and the long run to pay full attention to the reduction of malaria-related environmental hazards wherever conditions favouring them occur. Particularly in irrigated agricultural schemes the planning of all water-related actions should include malaria prevention measures and consider the necessary costs. This would also better focus the actions towards investments beneficial for crop production.

Problems with the irrigation water storage capacity in the Khasm-al-Girba dam were most likely the main responsible factor for the increase in the malaria incidence in the New Halfa Scheme, as irrigation water had been stored in the canal network inside the agricultural scheme instead of the sediment-filled dam. However, the results of the present study indicate that it is highly likely that the prosopis invasion with all its accompanying side effects also contributed to the increase in malaria incidence in the southern parts of New Halfa. This can be seen from the survey comparison between the prosopis-invaded southern parts of the scheme and the northern parts that represented a situation without prosopis.

In the Gandato Scheme case no clear indicative trends can be seen regarding a linkage between prosopis invasion and malaria incidence. In this scheme there was less of stagnant water around, and most of the prosopis was outside the irrigation canal network. It appears that there were other, clearer causes for the slowly increasing malaria incidence in the area. These causes were more likely related to new boreholes with storage containers with stagnant water and an overall decrease in the resistance against diseases. The latter factor could probably also have been related to increasing poverty, particularly among the part of the population that was directly affected by the sand invasion with all its accompanying economic burdens and health stresses. Possible consequences were already seen in the obviously reduced life expectancy observed in the unprotected part of Wad Killian. However, all these observations would require additional scientific research and relevant medical expertise for confirmation.

While discussing the prosopis impact on malaria it is worth remembering particularly in the New Halfa Irrigation Scheme the management practices were also responsible for a substantial part of the health problems within the Scheme. Sudan was still in 2000 a country which allowed the use of many hazardous chemicals, such as DDT, as pesticides in agriculture (Listorti and Doumani 2001). The local veterinarian, tenants and landless persons in the New Halfa Scheme stated during the data collection several times that even recently the area had been sprayed with DDT and other pesticides from the air, and the chemicals were even dropped directly over the villages. Affected inhabitants and especially the workers applying pesticides are normally at a risk primarily from inhalation of and skin contact with pesticides (Philip 2001). In the scheme area hazardous pesticides with long-term effects would have been found in cultivated crops, the livestock, wild animals, as well as in humans, particularly because of the household use of the water in the irrigation canals. This use was necessary as no river or ground water was available close to the villages (according to the scheme management, ground water occurred at a depth of 75 to 100 m). The New Halfa town veterinarian stated that a major cause for livestock deaths was the use of various pesticides in the scheme, while no hazardous contractable animal diseases were found. The apparently scarce populations of rodents such as rats and mice may also be a plausible reason why there were so few snakes in the irrigation scheme area. After a ban on DDT utilization there have been other chemicals sprayed every year from the air, out of which at least some can be assumed to be hazardous for both humans and animals in the scheme.

## 6.5. Overall synthesis of the research

### 6.5.1. Environmental/ecological economics and environmental management in Sudan

The degree of inter-linkages between economic and ecological systems may vary, but it is hard to find ecological processes that are not impacted by economic activities, or economic activities that are not only influenced but even constrained by the natural environment (Perrings 1995). Such an inter-linkage can well be called ecological economics, which according to Daly and Farley (2004) is a research field that is highly multi- and trans-disciplinary and where practitioners have to accept that disciplinary boundaries are mostly academic artefacts irrelevant outside the academic world.

The main focus should instead be on identifying relevant tools that best provide realistic and pragmatic values for the goods and services under valuation. The approaches and the angle of view for conducting of the present TEV study are supported by a conclusion by Farley et al. (2005), according to which the task of the ecological economist can be seen as solving problems in the face of high complexity and as mastering of the challenges met in such multi- and trans-disciplinary expertise areas. This kind of study needed pushing forward in many disciplines on a broad front simultaneously and interactingly.

Some well-known environmental economists have recently expressed their criticism on the state of environmental economics in general. An apparent lack of pragmatism and realism has been present in much of the work in the field, which has got reports such as those by Byron and Bennett (2002), Underwood (2004), Daly and Farley (2004) and Farley et al. (2005) to comment on the issue. Kaimowitz (2002) also stated, regarding the valuation of tropical forests, that recent economic analyses have tended to come up with much lower figures for forest environmental services than were normal one decade earlier. He explains this as inability to properly capture all the non-monetary values of forests. Both decision-makers and the public at large may be confused by the diverging results by pragmatists and theoreticians, and this has been causing both delays and credibility problems when challenging environmental issues need to be resolved for specific cases. This particular study was conducted in such a way that environmental services that are difficult to distinguish from each other either in monetary terms or conceptually, or in both ways, were left unmonetized in case it could be anticipated that the achieved valuation result would have credibility problems. Care was instead taken to separate the concrete costs and monetize them, while leaving some positive but abstract impacts as mere descriptions.

The current environmental challenges in Sudan need to be tackled in ways that take full account of practical realities. This may create a conflict between human needs and ecological constraints that have to be solved through a trade-off between short and long-term objectives among multiple stakeholders. Such conflicts belong more to politics than to science and should be solved outside the academic arena. Turpine (2003) concluded, for a South African case, that solutions to environmental problems in the country are constrained by the fact that the social values of biodiversity are almost unknown there, and thus the potential impacts of losses of biodiversity on social well-being are not properly recognized. The issue of the local population's environmental awareness and nature valuation would need to be investigated more thoroughly also in Sudan.

A study conducted by Lynam et al. (2003) indicated that in Mozambique the rural poor population had only use values for the nature surrounding their village. The value was highest for land from which the villagers could collect most of the resources needed for the livelihood, disregarding, for instance, the landscape aesthetic values. The two selected framed research sites in the present study conducted in Sudan appear to have been better connected to the national and local cash economy, and although the same elements of nature value appreciation as those described above for rural Mozambique could be seen at both sites, the environmental perceptions were slowly changing. Unfortunately it appears that this change in environmental awareness has to develop through a more technocratic development process, so as to build up at least some small wealth before the nature values can be fully appreciated in their own right. The spread of desertification and the climate change may force and accentuate substantial changes in these attitudes in the coming years, and the case study areas in Shendi and New Halfa in Sudan are no exceptions to this development.

At the present time many administrators, managers and authorities at all levels in Sudan are frequently viewing the environmental concerns as luxuries that need to be postponed until a later stage of development. From the policy perspective it is important to understand who benefits and who pays when resources are used for various purposes, to the extent that the situation can be rectified to better benefit the whole affected population.

The environmental legislation in Sudan is only in the process of developing, as much of it has so far only been adopted from abroad and, therefore, the practical law enforcement work shows problems. There are many authorities involved at all levels which are not properly coordinated and which have divergent regulations. Bashir (2001) enumerated the following environmental laws and regulations that in 2000 were embodied in various sectoral legislations of the ministries of the federal governmental administration and which had to be adopted by state ministries in the 26 states of Sudan: 19 laws dealing with land tenure and land use planning, 10 on soil conservation, 4 on forestry, 9 on wildlife and protected areas, 16 on water courses, 5 dealing with marine resources and coastal management, 5 on livestock, 6 on hazardous substances, 4 on energy and mining, 10 on environmental health, and one on antiquities. This gives, at the national level, a total of 99 individual acts, laws and ordinances, and at the lower level of authority these had to be coordinated with similar legislation from other fields as well.

A new Environmental Policy Act was issued in March 2000, by the Higher Council for Environment and Natural Resources (MEPH/HCENR), that strived to coordinate the environmental issues among ministries. Recently, experts working for the Sudan government produced Sudan's first national communication under the UNFCCC, and the same administrative body has also recently coordinated the preparation of a National Environmental Action Plan (MEPH/HCENR 2003). However, the HCENR has not received sufficient funding from the government to implement the existing environmental plans, and the environmental sector therefore lacks proper coordination and falls between the diverging interests of other authorities[7].

An analysis of impacts from prosopis is always intimately connected with the even larger challenges of desertification and poverty. Therefore, omitting of these problems (bottlenecks) from the discussion eventually would not contribute to improvements in the local human well-being or to mitigation of other hazards for these people.

The current situation in Sudan in which prosopis is considered a weed only and therefore is excluded from the tree resource in national, regional and local level forest planning and management causes an erroneous picture of the status of forests in Sudan. The fact remains, though, that the local population in areas where prosopis exists mainly uses this tree instead of the local tree species, due to instructions given by village chiefs and foresters (cf. Salih 2000; also confirmed by own household surveys and observations). This means also that an area described in official statistics as devoid of harvestable wood resources may currently still have a supply that comes from "nowhere". Such statistics create false information for the planning of sustainable development. In a way Sudan may in this manner have been reporting to FAO and other coordinating international forestry bodies an over-estimated rate of deforestation, at least for some locations in the country.

There are currently weak incentives to manage the natural resources properly on common lands, and, further, there are almost no technical or institutional interventions that could be used to change this situation. Well functioning landscape management plans would therefore be needed that can sort out overlapping authority between various ministries and increasingly transfer the management of the local natural resources to the villages themselves, against full responsibility for land-use development. Both inside and outside irrigation schemes in the semi-arid and arid regions of Sudan there are normally fairly high human population densities and a substantial pressure towards

[7] Personal communication by a high authority at MEPH/HCENR in Khartoum in June 2004.

utilizing the scarce native forest resources in various ways. A short-term poverty alleviation scenario is often also causing a gradual degradation process that negatively affects both the biodiversity and soil erosion. Such collective degradation of open-access forest resources is in environmental economics known as the “tragedy of the commons”. To curb this process, special preconditions for collective and efficient forest management are immediately needed. Fast-growing tree species can be used to compensate for the existing discrepancies between the needs of the rural population and the insufficient forest production. Prosopis is a tree which can withstand intensive use without becoming depleted.

A high dependence of landless people on forests while poverty prevails is an indication that better employment options with higher economic returns are unaccessible to them. Currently too little is known of the potentials of forest resources to alleviate poverty, and both neglect and unrealistic expectations therefore coexist. Various population groups that are dependent on forest resources tend to be heterogenous in their interactions with forests. It is therefore important to distinguish these population groups in any one area for understanding the forest interaction of each group specifically and thereby enabling better economic support to each of them. National economic policies for some areas of Sudan are currently not sufficiently highlighting the most vulnerable population groups.

Alongside with the expansion of the agricultural landscape with all its biodiversity there has also been a process of trying to maintain the viability of the past physical and cultural landscapes in an ecozone which some decades ago was less harsh than today. Particularly during the last five or so decades, there has been a fast and steady desertification process ongoing over large areas in Sudan that only partly has been climatic in nature; the other part consisting of human-influenced degradation. In the case of the Shendi area in River Nile State, the current agricultural biodiversity in its broader sense has been useful for the upkeeping of a viable nature and a mind-pleasing riverine landscape. However, areas just outside the irrigated farmlands tend to be overexploited due to an increase in both human and livestock populations living permanently in the area (cf. Pimbert 1999). Riverine agricultural biodiversity landscapes are also enriched by numerous opportunities for micro-environments (cf. Chambers 1990) that still exist in the area and support the individual households in their livelihood diversification, as well as the biological stability as a whole. Without a bufferzone of prosopis between the riverine vegetation and the sand invasion area those landscapes will be difficult to maintain sustainably.

In the arid and semi-arid savannas in Africa there is almost no recharging of the deeper aquifers from rainwater which to a large extent evaporates or is lost as runoff flowing into wadis and onwards to rivers and lakes (Pereira, 1989). The groundwater recharge at the confluence of the Blue and the White Nile around Khartoum and from there further to the north is mostly based on water infiltrating into the ground on either side of the Nile over a width of some kilometres. Further, there are also old deep layers of paleo-groundwater remaining from the cooler and more humid Holocene era that forms a substantial part of the groundwater resources. These two water sources mix to some extent with each other, and at the surface the existence of rainwater flowing in wadis contributes to the dryland vegetation cover (Farah et al. 2000). A bufferzone with prosopis would be able to stabilize the hydrological and micro-climatic conditions better than the bare soil and to thereby expand the width of economically useable land on either side of the Nile.

### 6.5.2. Mitigation of desertification

UN organisations which proclaimed an International Year of Deserts and Desertification in 2006 (cf. UNCCD 2005) aimed with this campaign at focusing the world’s attention on the desertification problem, which is one of the major global threats to humanity and further aggravated by the climate change and losses in biodiversity. In countries like Sudan desertification is the foremost risk to a positive development process, affecting the food security, the human health and nutrition, the land tenure and thereby also the poverty reduction, the national security and the internal national stability. During recent years the so called Poverty Reduction Strategy Papers (PRSPs) have become important national tools for governments in many African countries by defining how poverty can be reduced. In fact, such stategic plans are commonly a prerequisite for international donor-based financing of development interventions. It is important to understand how forest resources are linked to poverty reduction at the local, provincial and national level in Sudan. Deficiencies have been demonstrated in such linkages in several African countries, but also means to improve the situation have been outlined (Oksanen and Mersmann 2003). Without proper knowledge that also includes the experience from other countries the implementation of new plans will fail.

Sudan is a signatory to the UN Convention to Combat Desertification since November 1995 (Gorashi 2001; UNCCD 2004). As an African signatory member country struck by desertification, Sudan needs to participate in sub-regional action plans (SRAPs) and prepare its own national action plan (NAP) against desertification. To be able to implement such plans Sudan also needs to identify the real causes of desertification and their mitigation possibilities, which have to be based on realistic views of the situation. Leaving out prosopis from the national forest resource inventory and not recognizing its existence particularly in Northern and River Nile States does not fulfil the SRAP and NAP preparation criteria and means that sustainable development these cannot be properly planned.

### 6.5.3. Bioinvasions and prosopis

Similarly to the South African situation (cf. Richards 2000), prosopis tends to die out in such areas in Sudan which have become too dry due to climate change or other factors causing severe droughts. However, prosopis still commonly persists in areas of low rainfall and expands into new areas where the native tree species are currently unable to withstand desertification but conditions are still favourable for the more drought-tolerant exotic species. However, due to the role of livestock in dispersing prosopis seeds, better range management would substantially reduce the speed with which prosopis is spreading, although also the wind and water flow many times contribute to its spread to new areas.

A striking fact is that the great majority of scientific articles about invasive alien species - especially articles describing theoretical modelling - mainly consider these species from a negative angle (e.g. Buhle et al. 2005; Finnoff et al. 2005; Saphores and Shogren 2005; Perrings 2005). A telling case was an earlier debate about invasive alien species in South Africa. Of several widely spread scientific articles written by South African researchers (e.g. Richards 2000; De Wit et al. 2001; Dean et al. 2002; Le Maitre et al. 2002; Hoffman 2003), no one had analyzed in a balanced and site-specific way how benefits and costs from so-called invasive alien tree species are accrued, and the depth of ecological knowledge and environmental awareness did not appear sufficient for an objective scientific article. A new search for such South African studies on the same topic by the researcher conducted in January 2007 would suggest that the situation has to a large extent been rectified during the last few years.

The South African debate, as it was conducted a decade ago, seems to have had a major spill-over effect on other African countries. Through personal communication with quite a few Sudanese forestry and agricultural authority persons and researchers it became apparent that the decree to eradicate prosopis in Sudan was a direct consequence of high-level official contacts between Sudan and South Africa after which the issuing occurred. Sudanese political authorities obviously need to show more independent thinking and broaden their sphere of knowledge sources in this matter, to an extent that ecological and environmental awareness is better and more objectively taken into consideration. The current refusal of the Sudanese agricultural sector to identify the problems correctly, especially concerning irrigation schemes, and the use of prosopis as a scapegoat for mistakes made, is becoming costly for the country and its citizens, particularly in Northern and River Nile States which really need the prosopis already existing there for protection against sand invasion.

A typical problem with assessments of invasive species is that there is a strong public-good element in their control (Perrings et al. 2005). A trust in market forces alone to control prosopis leads to an undersupply in the monitoring of the invasion. An overall monitoring of invading prosopis will be as effective as the least effective community member responsible for controlling it. Community members have diverse and constraining benefits and detriments stemming from the tree, as demonstrated by the present study, whereby the respective incentives for controlling it should also be different. Authorities which demand strict control may thereby insist on higher levels of environmental protection by each community member than these have incentives for, and thus, indirectly, this may spill over to community members who originally had sufficient incentives but eventually need more resources due to their neighbour's neglect in fulfilling their share of the responsibility. In case national, regional or local authorities have insufficient information to base their decisions on regarding prosopis management, it leads to one-sided actions that are counter-productive from a larger holistic as well as from a household financial viewpoint.

In many agricultural irrigation schemes in the arid tropics, increased salinity has been a result from many years of irrigation, with lower agricultural crop yields as a consequence. For instance, Stanton et al. (2001) reported from New Mexico, USA, that the local *Prosopis glandulosa* var. *torreyana* had invaded many such sites. The researchers were analyzing various prosopis cultivation alternatives and viable economic options for agricultural crop production under such conditions. Suitable products identified were, for instance, prosopis gums, prosopis pod fibre breakfast meals for human consumption, timber, and flooring materials. Noteworthy is also that in Al Hosh village of the Gandato Scheme in the present study there were a couple of tenant farmers producing timber-quality prospis on a rotation period of several years on fields that had lost at least part of their agricultural potential due to failing irrigation, invading sand or degrading soil conditions.

The local Sudanese landrace of prosopis may not be suitable for human food consumption, but for other alternatives it still offers attractive possibilities. Felker (2004, 2005) also concludes that the landraces of prosopis found in Yemen and in Africa may include individual trees from which both human food (with famine relief potential) and furniture could be developed. He also informs that research is ongoing in Yemen to chemically reduce the bitterness of the pods in the landrace prosopis. The work conducted in Yemen is likely to be of high interest for Sudan as well.

While collecting field data for the present study the researcher observed on several occasions that other tree species had reconquered at least partly some growing space from prosopis. One such site was the live fence around the Soba tree nursery area next to the Forestry Research Centre premises south of Khartoum, which in the 1980s and 1990s used to consist mainly of prosopis. This fence has in a natural ecological succession process during the last decade or so become mainly dominated by *Acacia seyal* (typical for the clay plain forests), with only a few prosopis individuals remaining. This situation had also been observed by researchers at the Sudan University in Soba.

In the framed research area in the New Halfa Scheme there were also examples of other species succeeding prosopis. As presented earlier, prosopis had been introduced to the scheme for a live fence around a crop species trial and horticultural area in the early 1960s. In 2004, this crop trial and horticultural orchard of some 300 feddans that happened to be situated in the actual framed area of this present study, was almost the only site left in the area without invading prosopis. Only a small corner of the horticultural orchard had some prosopis, and the live fence had a rich variety of other tree species than prosopis. The guards of the area informed that they had easily weeded away the prosopis seedlings from the area during all these years. This site is perhaps also an example on the role of soil and land degradation in the invasion of prosopis. At several other sites in the framed area that were invaded by prosopis one could also see how *A. seyal* individuals were raising their crowns above the lower prosopis shrubs and in some places where there had been charcoal-making from prosopis there were small patches of acacias like *A. seyal* and *A. mellifera* taking over the site. Similar cases of shifts in the woody plant composition in the vegetation cover from prosopis towards native species were encountered elsewhere in Sudan as well.

#### 6.5.4. Prosopis as shelterbelt species

The present TEV study indicates that the arid and semi-arid sandy areas of Sudan bordering the Sahara desert are cases for favouring the prosopis tree. The beneficial impacts of prosopis as a shelterbelt species are in fact completely outweighing the detrimental impacts once the issue is analyzed holistically. The problem to date has been that the agricultural authorities mostly recognize the concrete expenses of prosopis, while the more complex and sometimes abstract beneficial impacts remain unrecognized. There may also be cases where politically strong opinions over-rule the politically weaker ones in this respect. Several foreign aid-funded international community forestry projects in Sudan and elsewhere have conducted trials, as presented earlier in this study, which show that prosopis is by far the best-performing tree species in desertification mitigation and control.

Some experts employed by international projects in Sudan reported in the 1990s (cf. Branney and Connelly 1990b; Bristow 1996; Mutsambiwa et al. 1998) that, before the prosopis eradication decree in 1995, the farmers of the Shendi area had no doubt what species they prefer: prosopis was favoured by 73% of the population for shelterbelts and *Eucalyptus camaldulensis* and *Pithecellobium dulce* for on-farm windbreaks. Other species – also exotic – favoured for village use were *Azadirachta indica* and *Leuceaena leucocephala*. The native species *Acacia tortilis*, *A. nilotica*, *A. seyal* and *Faidherbia albida* were also liked around the villages. ElRahman (1991) studied the opinions on prosopis among the local population in the Zeidab irrigation scheme in 1989. He found that about 75% of the household heads stated that prosopis was more favourable than costly to the area. The disadvantages found were the same as also identified in the present study.

Furthermore, among the 100 households interviewed by ElHassan (2004) in the Matemma area villages opposite Shendi at the Nile, 92% of the households had some degree of sand invasion of their houses and yards. Of these randomly interviewed households, 59% had a high degree of sand invasion, 30% had a moderate one and 3% had a minor invasion. Additionally, the same author reported that 47 of these 100 households had their farms affected by the sand covering the fields and the irrigation canals. All but one household had considered prosopis shelterbelts effective in stopping the sand from invading houses and agricultural fields, and 68% of the households wanted to keep their prosopis shelterbelts. Further, 69 of the 100 households considered prosopis as the best choice of tree species for shelterbelts in the area.

ElRahman (1991) analyzed the household interview data based on 55 settled farmers (mainly Gaalian and Shaigyan) and 45 pastoralist households (mainly Hassanian, Ababdan and ZuAdaban) collected in 1989 in the Zeidab Irrigation Scheme some 80 km north along the Nile. The grazing of the livestock was according to 62% of the households interviewed taking place only in the prosopis shelterbelts of the scheme, while 32% of the rest of the households fed their animals before the harvest in the prosopis shelterbelts and after the harvest in the field. Of the remaining 6% of the households interviewed, 2% claimed that they fed their livestock only at home, while 4% also fed their livestock outside the scheme area with the natural arid savanna vegetation. Some 86% of the household heads had further stated that prosopis pods were the principal parts for livestock fodder, while the remaining 14% of households assessed that the green leaves were as palatable, particularly for camels, sheep and goats.

ElRahman (1991) also concluded that prosopis was considered by 94% of his interviewed household respondents to fatten the livestock for meat production in case some other feed was also added. Milk production was, however, the main purpose of livestock production for 63% of all the interviewed households. The shelterbelts established in the mid 1970s were, according to the households interviewed, able to raise the annual household livestock income in the area.

Since the mid-1990s the Agricultural Research Corporation in River Nile State has also tried some introduced Australian acacias as windbreaks, but these tree species must reach the groundwater to survive in the area. Furthermore, several agricultural and forestry field managers confirm in their reports that shelterbelts are crucial for almost any agricultural activities in River Nile and Northern States (Branney and Connelly 1990 a, b; Bristow 1996; Mutsambiwa et al. 1998; Doka et al. 2003; ElHassan 2004). Although this information is widely understood and accepted, it has not been incorporated into the normal agricultural practices in a coordinated way. One reason for this may be that the most prominent tree species for shelterbelts in this area is prosopis, but there is the ban on the tree which effectively constrains the extension work and the innovativeness in shelterbelt construction, as nobody is officially allowed to manage shelterbelts with prosopis.

The performance of the Shelterbelt Project in the Shendi area was evaluated in 1995 by the SOS Sahel organization together with the local FNC office. It was found that in villages where the village elders were involved in the shelterbelt establishment activities there was a success (Bristow 1996). Wad Killian village was one such village, while the shelterbelt activities outside Al Hosh village basically had failed. In the latter village the households affected were newcomers mainly belonging to the Hassanya or Ababda ethnic groups, while the original Gaalian and Shaigyan villagers were less affected by sand invasion. The latter ones had always been the politically strongest groups in the village, but they had had less interest in planting shelterbelts, and the watering of the shelterbelts had to some extent also been neglected. However, from the harder and more compacted and bare soils outside Al Hosh it could be judged that shelterbelt establishment was also a more challenging task there than in areas around Wad Killian and Tundub with their more undulating sand dunes and looser soils.

### 6.5.5. Recommendations for the New Halfa and Gandato Schemes concerning prosopis

The situation in New Halfa Irrigation Scheme is complex and one simple right recommendation does not exist. The first issue is that the problems with prosopis in the New Halfa Scheme are linked to other major problems. These other problems are, for instance, the siltation of the Khasm-al-Girba dam and storing water in the canal network, crop selling prices and markets, the overall agricultural policies, uncontrolled range management, unchecked growth of the landless population inside the scheme and poverty and severe health problems among all population groups. There is also a lack of other woody vegetation, outdated land tenure arrangements around the scheme, as well as land degradation, desertification and an ongoing climate change. Prosopis has been given the role of scapegoat for most of these problems which actually are management, environmental awareness, and financial constraint problems.

If a TEV analysis had been made for the framed area inside the New Halfa Scheme it should preferably have, at the first stage, comprised four sets of alternative TEV analyses – one for each respective population group and, at a second stage, a combination of them all into one comprehensive TEV study. One would also need to separately decide first on whose interests should be incorporated in the decision-making. Should only tenant farmers live there, or should all the other three landless or nomadic population groups also be allowed to live there as was the prevalent case? If so, how many households of these other groups would then be allowed to stay inside the scheme area? Are there sufficient livelihood opportunities for the landless people elsewhere and is disregard of these population groups' interests directly leading to starvation and poverty? The surveys conducted and the information compiled on the magnitudes of scale of prosopis impacts on each population group in the area already provide satisfactory answers for decision-makers, even without a more elaborated study. The present work presents calculated monetized benefits and costs from which answers sufficient for finding the needed political and technical solutions can be derived.

In case prosopis were eradicated inside the scheme, there would be a need to establish and maintain a sufficient tree nursery capacity and to carry out annual plantings with large numbers of tree seedlings in the area. Native acacia species would not grow fast enough to cover the wood and NWFP resource needs inside the scheme. Therefore, fast-growing exotic trees are needed, but it would not be wise to plant thorny varieties or species, as these are difficult to manage, if thornless alternatives were made available. One solution would then be to plant Australian thornless acacias (such as *Acacia auriculiformis* which has gained popularity in South and Southeast Asia), but this means then most likely a need to irrigate such trees for part of the year to increase their survival and growth performance.

A World Bank report (WB 1992) and an older consultancy report for the Ministry of National Planning (Agrar- und Hydrotechnik 1978) have indicated that the scheme has since its establishment in 1964 had management problems. Therefore problems in the scheme should not just be blamed on prosopis, which only acts as an indicator of the management problems. Already in 1976 it was recognized that the Khasm-Al-Girba dam had been to a large extent filled with sediment. Still it was not until 2003 that the dam was restored to a size slightly larger than the original one in 1964. The sedimentation is assumed to come with the Atbara river from Ethiopia, which is probably partly true. However, large tracts of land around the western side of the Khasm-al-Girba dam are severely gully-eroded, and one can only wonder where the eroded soil has been transported in these years. It is more than likely that this eroded soil has also contributed to the siltation of the dam. Further gully erosion could have been mitigated by such tree species as *Acacia tortilis* or prosopis established in the area. These trees have lately established themselves here, but more trees are definitely needed to effectively slow down the erosion.

It is less feasible to plant prosopis on clay soils, since many of the benefits from prosopis in desertification-prone areas in Sudan are related to the shelterbelt effects against sand invasion and wind. On clay soils other fast-growing tree species that are easier to manage should be preferred. However, as the other species need more tending at the establishment stage, they will not survive and grow sufficiently well without the actual provision of such tending. Without the tending of seedlings and stands, prosopis would be the cheapest wood resource option also for this area, since it regenerates efficiently even without such efforts.

The New Halfa Irrigation Scheme received in 2004 – 2005 from the federal government of Sudan tens of millions of US dollars worth of money for a campaign to eradicate the prosopis from the scheme area. In early 2006 information from the New Halfa Scheme and visiting experts tended to describe the situation as at least temporarily being under control[8]. The question is whether the eradication will have a permanent effect and for how long a time, or whether prosopis will start resprouting and germinating from soil seed banks. It is also not clear whether there are any plans by the scheme management for substituting prosopis with some other fast-growing tree species that would also provide shade so as to prevent the prosopis seedlings and coppice from taking over again. Experience from elsewhere in the tropics would forecast that it will not be easy to get completely rid of prosopis in a given area (Otsamo 1993; Johansson 1995). It is, though, clear that species such as prosopis will create substantial problems for agricultural practices inside irrigation schemes if not controlled properly, and attempts to mitigate their impacts on agricultural fields are essential for the profitability of the schemes.

Even in the case of the Gandato Irrigation Scheme the landrace variety of prosopis should preferably not be bordering the irrigated fields, but rather, a less thorny fast-growing variety or species should substitute the present prosopis. Dead fences made from prosopis could still be used around the irrigated fields to keep the livestock from entering the schemeland and the riverine zone. Shelterbelts against the bare drylands from where sand invasion is encroaching should preferably be with prosopis, and prosopis should also be allowed to invade the bufferzone.

The present study is not sufficient for a common generalization of the results to cover other areas in Sudan with specific prosopis-related problems. It is, however, apparent from casual field observations that the prospis along the Red Sea coast may not pose serious problems. The coastal soils are saline, and prosopis may be able to reduce the salinity of the shoreline, and after some period of time the trees could be harvested and other species could be planted in the possible future seashore gardens surrounding leisure houses or resorts along the shoreline. ElSiddig (1998) has expressed thoughts in the same direction for this particular area, and Geesing et al. (2004) are harbouring similar ideas for the Lake Chad shorelines in Niger. The cases of Tokar and Kassala city surroundings are complex and need specific targeted assessment to determine how to tackle the prosopis issue there. In areas where prosopis is not already established, an early warning and detection system should be in place and enforced. For each location the situation should be considered separately, and the response for monitoring the situation should thereafter be tailor-made to suit that area.

### 6.5.6. Management recommedations for prosopis

In New Halfa and elsewhere in Sudan there are numerous foresters and forest technicians who know prosopis well. The New Halfa scheme had commissioned the FNC to prepare an extensive literature review on prosopis which is objective and well-prepared and also includes information on how to manage prosopis or eradicate it from the scheme (cf. Mageed et al. 2001). A part of the problem, though, has been that these professionals have not in practice been allowed to handle the situation; instead, the agricultural sector has over-ruled their expertise. Better results could have been obtained by first conducting multi-disciplinary brainstorming on the issues and then starting the solving of problems from the right end.

[8] Personal communication by New Halfa Scheme management and the UNEP project preparation team in Sudan.

Several researchers and practical forest managers have been reporting on the management of prosopis stands in Sudan as referred to in the introduction chapter. The present results tend to confirm the earlier findings. Pruning of prosopis stems should be taken seriously and seen as a means of reducing the damages from too widely spreading prosopis shrubs. If the whole tree is cut down, new sprouts will replace the former stems, while an erectly pruned stem will curb any further sprouting due to the shade from the already standing tree. The standing tree will then further concentrate its annual growth more to the vertical woody bole than to the small and heavily thorny horizontal branches near the ground. Trees could even be pruned on one side only, for instance, along the roads and in other places where bushy trees are obstructing movement while also providing protection from sand and wind.

A management practice that to some extent is related to the above but not much promoted is based on the researcher's own observations all around in Sudan confirming that individual trees often carry their own pattern of thorns. Trees in close spacing can have small, medium or large thorns on apparently random basis, but it appears also that especially in River Nile and Northern States, forms of the landrace occur, which, on average, have smaller thorns. This observation was also confirmed by the local FNC foresters. Many individual trees had weak thorns of only a few millimetres in length, and one could, for instance, in places easily squeeze through a thicket of prosopis without getting stung or caught by thorns. In areas where prosopis is a nuisance and should be eradicated it would therefore be wise to remove those prosopis individuals which have large or medium-size thorns, while leaving the tree individuals with small thorns. Such less thorny individuals would then prevent the more thorny ones from growing in their shade, while the already standing trees or even the whole stand would be easier to manage.

There is a trend of declining use of woodfuels in Sudan among the wealthier households both in urban and in rural areas. The wood energy is seen as inferior to liquid gas or electricity. This decline will generally be slow, although some households have already ceased to use woodfuels. A specific reason for the decline in wood use is that Sudan possibly has Africa's largest reserves of oil, and this may now cause setbacks in the control of prosopis, as obviously the simplest option to constrain its spreading would be through its utilization. It would be important to maintain a large-scale utilization of prosopis that can control the stock to such an extent that an optimum amount of benefits would accrue from the species. A prosopis-based wood industry could, for instance, produce flooring material for a luxury export market, as prospis wood belongs globally to the most valuable wood materials after it has been processed properly (cf. Pasiecznik 2001; Felker 2003, 2004).

Wherever possible, the range management in Sudan should be better planned and monitored in respect to prosopis, as the livestock is the main agent for spreading the tree species. In some places it could be considered whether grinding of prosopis pods for fodder could be organised, with the aim to reduce the dispersal of prosopis seeds and prevent its invasion in unwanted places.

## 7. CONCLUSIONS

The present study confirmed an overall assumption that prosopis has different benefits and costs at different site conditions in Sudan. A Total Economic Valuation (TEV) study for the Gandato Irrigation Scheme shows, that the benefits from prosopis were completely outweighing its detrimental effects in this particular area. In the financial year 2002-2003 the net average annual benefit from prosopis was 607,000 SD per household for impacts that could be monetized, and a monetized benefit/cost ratio of 46 for the area was calculated. On top of this there were additional beneficial impacts that were difficult to quantify and monetize which could be assumed to considerably increase the monetized net benefits when credibly valuated.

The whole riverine area from Kosti in White Nile State up to the Egyptian border in Northern State is confronted by sand invasion in the form of sand dunes or sheet sand. Results of the present TEV study indicate that this whole riverine area along the Nile would be much favoured by shelterbelt protection with prosopis or a similar tree species that can stop the sand from invading villages and the economically important fertile agriculture ecozone from degradation in terms of both land quality and biodiversity. No native tree species growing in the area is able to provide these sand and wind protection services as well as prosopis.

For the population in the Gandato area near Shendi, prosopis was found to be a small cash expense and cash outlay for almost every household in the area. It provided a substantial part of the energy needed in the area and, on average, 205,000 SD worth of annual subsistence income for an average household through free grazing forage for the livestock alone. The current livestock population in the region would collapse without this prosopis forage opportunity.

In New Halfa there was a high degree of prosopis dependence among the western and eastern Sudanese landless groups as well as the nomads. For the western Sudanese landless population prosopis was a substantial cash income source, and for all landless groups it was important for subsistence income in the form of free-grazing forage, wood energy, and construction materials. Although many landless households considered themselves as farmer families, their income related to prosopis was larger than that from crop cultivation.

For the tenant farmers in New Halfa prosopis was a cash expense in several ways. It substantially reduced the tenants' profits from crop cultivation due to increasing ploughing and maintenance expenses in prosopis-invaded irrigated fields and irrigation canals. It also caused costs for employing labour to weed seedlings and cut larger trees as well as thorn injuries that needed medical attendance. Additionally, many households also voluntarily chose to purchase it in the form of charcoal, fuelwood and poles, although these much needed products could be obtained free of charge by the households directly. Still the accumulating cash expenses and cash outlays were in many cases of about the same size or smaller than the total subsistence income from prosopis through livestock forage and wood energy.

In the agricultural irrigation schemes where water was insufficiently managed and in places of stagnant water, unmanaged dense stands of prosopis appeared to increasingly provide habitats for water-borne vectors of diseases and at least of malaria. There was a clear difference in the incidence of malaria between the prosopis-invaded southern parts of the New Halfa Irrigation Scheme and the northern, non-invaded parts of the same scheme. Malaria has a serious long-term detrimental impact on the local population in New Halfa. In the Gandato Irrigation Scheme, no connection between prosopis invasion and malaria incidence was found.

Prosopis resources in the sandy areas of Sudan should be included in the official national forest resource assessment, as these resources are the main wood energy and fodder provider in these particular areas and needed for stopping the sand invasion. On clay soils prosopis should as a resource be considered more carefully and site-specifically. Sudan is unable to fulfil its obligations to implement the international agreements to combat desertification and to promote sustainable dryland development without a correct identification of the causes for desertification, environmental degradation and poverty. Proper management of prosopis as an invasive alien tree is an essential part of this task.

The present study also highlighted how an overall research process for a total economic valuation (TEV) investigation of an invasive alien tree species could be achieved in practice. It also confirmed what many community forestry practitioners and researchers in Sudan have already previously suggested, i.e. that prosopis is the best-performing tree species in combating desertification in Northern State, River Nile State and probably also in North Kordofan State. In addition, the present study also provided an economic justification for that conclusion. The insistence of the agricultural sector in seeing prosopis as a scapegoat for sectoral management failures will on the long run be extremely costly for the whole country and for the populations living in the arid and semi-arid sandy soil areas in particular. It is also difficult and costly to eradicate prosopis on sites which provide favourable growth conditions for the species. Therefore it would be wise in many areas to focus on the management and utilization of prosopis, so as to derive an optimum amount of benefits from the species, instead of considering it as an indication of poor management and an object of eradication efforts.

Ecological (or environmental) economic analyses on the role of prosopis in the arid and semi-arid ecozones in Sudan or elsewhere should be implemented using site-specific, scientifically verifiable and realistically monetized values. In particular, it would be essential to distinguish between sand and clay soil conditions in such analyses. Impacts that are clearly “positive”, but difficult to monetize credibly also have to be described and listed. Values should be credible and based on statistically representative samples of the economic premises of the local households and on their interaction with the micro-economic markets at the study site. Furthermore, the practical element is important, since the valuation approaches should also be easily applicable, fast to execute, and affordable by the authorities and the managers, so as to motivate them to use the results in the sustainable management of dryland resources.

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## ANNEX A

### Additional facts on malaria in Sudan

According to Wernsdorfer (2002), Adeel (2002), and Mashadi et al. (2002), malaria is the leading cause for morbidity and mortality in Sudan. It accounts for 20 – 40% of all outpatient attendance, as well as approximately 30% of all the annual in-patient capacity of the Sudanese hospitals. The annual number of deaths from malaria in Sudan is estimated to be about 35,000, which was approximately 70% of all malaria-related deaths in the whole Eastern Mediterranean Region under the WHO administration in 2001. Almost the whole Sudanese population is at risk for malaria, although at varying degrees. *Plasmodium falciparium* is by far the most common parasite species, accounting for some 90% of all malaria cases in Sudan. In eastern and northern Sudan, *P. vivax* and sporadically also *P. malariae* occur.

Statistics from 2002 for the northern half of Sudan, which was not much affected by the continuous fighting in southern Sudan, show that 16% of the population was less than 5 years of age, 45% of population was less than 15 years of age, 51% of the population was between 15 and 60 years of age, and only 4% were older than 60 years. The life expectancy was estimated to be 56 years, while the disability-adjusted life expectancy was calculated to be around 43 years. The maternal mortality rate was 36 per 10,000 live births, while the infant mortality rate was 108 per 1,000 births. The under-five-year mortality rate was 157 per 1,000 live births. The very significant share of children and bearing-age young women of the population imply induced high needs in terms of child and maternal health care (El-Idrissi 2003).

In areas of stable endemic malaria transmission about 25% of the mortality of all children under five years of age has been attributed directly to this disease (Sachs and Malaney 2002). Parents faced with high treatment costs are reluctant to bring in their children to hospitals until the children are too ill to be treated successfully; this delay in treatment is responsible for many deaths in malaria (Whitty et al. 2004).

The global distribution of the gross domestic product (GDP) in 1995, adjusted for the purchasing power, indicates a strong correlation between malaria and poverty. The average GDP income difference (adjusted to give the parity purchasing power) between malarious and non-malarious countries in 1995 indicated that the latter had a five times higher income than the former in the tropical and sub-tropical zones. The non-malarious countries studied also had, during 1965 – 1995, an annual economic growth rate per-capita of 2.3%, while the malarious countries had experienced an annual GDP per-capita growth of only 0.4% during the same time period. Studies have further indicated a particularly heavy economic and social burden of the poorest households to be caused by malaria. School-aged children are often suffering from malaria, which is resulting in absence from class. Adverse effects on childrens' education will go far beyond the time lost in school, as absenteeism increases the failure rates, repetition of school years and dropping-out from school. Further, malarious children have often a lower nutritional status than the non-malarious children, which can impair the brain development of the former group of children. Additionally, child-bearing women have lower immunity for malaria than the rest of the adult population, and malaria-related anaemia of the mother is often related to low birth weights among infants. Malaria is often also lowering the resistance against other illnesses, and any proper assessment of the economic burden caused by malaria should therefore include estimates of the costs associated with these illnesses as well (WB/RBM 2001; Sachs and Malaney 2002).

## Annex B. Study on resettled and other households with past sand-invasion problems

Apart from the interviews in the research villages, information was also collected on households that had already moved or that had earlier been in a similar situation as the currently sand-invaded households were in. This enabled a better understanding of the whole process of leaving the sand-invaded villages and of the relief of being rescued from acute sand invasion. In the Banat al Hamda part of Al Hosh village, the names of five resettled household heads were identified. The Banat al Hamda villagers informed that most of these households were close kin and had all moved to Shendi where they now lived. Two of the household heads were in 2004 said to be working as donkey cart drivers at the market in Shendi. One of the resettled household heads was eventually found at the said location and he directed us to his house in a newly built suburban part of Shendi where his wife could be interviewed while he was busy working.

The suburban area where the donkey cart driver lived had been built in the last few years, and each housing estate consisted of one-floor family houses with a yard and a wall surrounding the houses. The family in question had moved to Shendi eleven years before the interview took place, and this household was the first of the five known kin families that had moved to Shendi from Banat al Hamda. Both the husband and the wife were uneducated people, and the husband had in Banat al Hamda worked as labourer, but could not get by on the low income while having acute sand invasion in his house. Since the arrival in Shendi he had worked as donkey cart driver for a salary which in January 2004 was 15,000 SD/ month. During the first ten years the family lived on rent at various addresses for about 5,000 SD/ month – sharing houses with brothers' and neighbouring families. At the time of the interview there were five other families from Banat Al Hamda which lived in the same suburban area. The other households had arrived in Shendi during the last six years, and the latest family only a month before this interview took place. Life had started to feel better in Shendi than in the village some five years ago when the kin families moved in, and water, electricity and school came to the neighbourhood.

The other donkey cart driver's family had resettled in the suburb some four years earlier. During the first year the family had rented a house for 5,000 SD/month, but during the two following years the family had lived for free in the husband's brother's house and, since one year ago, started to build their own house, which was not yet ready. This new house was built in the yard of a good friend, who was not from Banat al Hamda. The family lived now in the unfinished one-room house and shared the kitchen with the other family. The new house was built of mud bricks and did not look very durable, although neat and of similar type as other houses in the area. The reasons for leaving Banat al Hamda had been the sand invasion and the low income level in combination. Four of the five first resettling households were about to build their own houses in similar fashion as this household, while the last one was living on rent like the newly arrived household.

The suburb had been connected to the city infrastructure three years earlier, although the home was still waiting for the electricity to be connected. The wife in the second household stated that life started to feel better than in the village three years ago when the infrastructure reached them and some of the younger children could start the school. The elder girls (the eldest daughter was 15 years) had never attended school even in Banat al Hamda. The fact that at least some of the children could go to school was an important factor for the well-being of the family. These families' former house sites in Banat Al Hamda were visited a couple of times in passing-by by the researcher in January 2004, and almost nothing was left of the oldest house ruin or the other kin families' former houses, which the invading sand had broken down to the ground. According to the housewives living in Shendi, there were in January 2004 several more Banat al Hamda families seriously thinking on leaving the village and settling in this area of Shendi. For all, the foremost reason had been sand invasion, but mostly in combination with the low income opportunities.

In addition to the two Shendi household interviews four households that currently lived in Khartoum North (specifically in Um Dhiraiwa, Daroshab, and Shambat) were a similar way interviewed. The household respondents were first met and picked up from the main long-distance bus stop in Khartoum North. These particular households originally came from a village near Berber, from outskirts of Berber town, from Ad Damer and from the small town of Mahmya, respectively, which all are situated in River Nile State. The towns of Mahmya, Ad Damer and Berber are situated some 80, 200 and 300 km from Khartoum along the Nile to the north. Each household had its own story how it became resettled in Khartoum North. In all interviewed cases there was a male in the household (husband or son) who had come first and started to look for jobs and at the same time conducted some reconnaissance for resettlement. This process could have taken up to six years before the actual resettlement of the whole family.

The first arriving adult male normally lived first in temporary accommodation like a house under construction, or in some relative’s or friend’s house while establishing himself in Khartoum. Once he had established himself with permanent salary and housing, the family had moved from the village to join him. The family property consisting of irrigation land, livestock, own shops and houses in the villages, was gradually sold during the last two years before moving. Many of the resettling households had waited with moving for their children to finish at least the primary school, as education was much more expensive in Khartoum. One of the four households that could afford higher education costs moved to Khartoum for the better education there. A reason given by almost every household was that the parents wanted to give their children a better life. When the families moved to Khartoum they often took the grandparents with them. In one of the four interviewed cases the move to Khartoum took place immediately after the grandfather had died.

Some of the households had not yet achieved a feeling that life was better in Khartoum North than in their former home village or town in River Nile State. One merchant family had been able to pay for its own house in Khartoum North, while the rest of them lived on rent. Occasional and even sometimes continuous private cash remittances from relatives and friends in Khartoum and from the home villages also played an important role for some of the households. These four households had all some petty business work or had civil servants in the families, which provided most of the income. Some additional small income was also obtained from jobs as night guards or other lowly paid employment work.

Both in Shendi and in Khartoum North there were also some real-estate middlemen interviewed and asked about rent levels, house prices, income opportunities, and the professional working background of the immigrating households. The information obtained from these real estate people confirmed that from the immigrating households and vice versa. The monthly income level in the Khartoum area was higher than that in provincial towns and villages. The normal monthly wage for a labourer could go up to 35,000 SD (2.3 – 3.5 times the Shendi wages), while many civil servants could earn up to 50,000 SD (1.4 – 2.7 times the Shendi wages). Small-scale business could provide an income up to about 100,000 SD (1 – 4 times the Shendi area income) a month. According to the real estate people, very few resettled households could earn more than that upon their arrival in Khartoum. As compared with the housing expenses in Khartoum, these incomes were too low to enable purchasing of housing land and building a family house in the greater Khartoum area (the Khartoum suburb housing land and house prices were about 10 times higher than those in Shendi). Therefore most immigrants would have to live on rent for a long time, if not for the rest of their lives. However, one cannot tell what the future will bring for anyone. A girl might marry rich in

Khartoum and a son could get a top job in business or government, or vice versa, and these persons could then better support also their close kin.

A few households from other villages in the Shendi area outside the framed area in Gandato Scheme were also interviewed. These households came specifically from the Taragma and Al Abdutab villages which had previously been without prosopis shelterbelt protection. The households from Taragma stated that after the shelterbelts of prosopis provided protection for the village, households had started to move back next to the shelterbelt where the former sand invasion edge and invaded houses had been located.

A good example for the whole area on the importance of the prosopis shelterbelt effect was provided by the situation in Al Abdutab on the western bank of the Nile some five kilometres north of Shendi downtown. The village was completely invaded in 1933 by a large sand dune from the desert side in the west, which forced the whole village to move closer to the Nile, and the same had happened again in 1966 (ElHassan, 2004). The same was further about to happen again in the early 1990s, but this time the SOS Sahel (an international NGO) came to the rescue and collaborated with the Forests National Corporation. Together with the villagers shelterbelts with prosopis were established on the western side of the village in 1991 -1992. The villagers and the local FNC foresters from Matemma and Shendi informed, further, that two years later the sand dune outside the shelterbelt became some 20-25 metres high. The shelterbelts were able to withstand the sand dune, and after a while the sand dune became spread out in other directions. Currently the dune was much lower and the village was intact. The previous village site from 1966 could be found under several meters of sand, and there one could look into a house ruin from a hole in a roof.

Two full household interviews were conducted in Al Abdutab, and the villagers stated, among other things, that since the shelterbelts became well established, they had been able to sleep better as the imminent danger of sand invasion was not there anymore. Al Abdutab is part of an irrigation scheme that includes lands of several villages, and in January 2004 the scheme appeared to have the least severe sand invasion in the Al Abdutab area. The neighbouring villages have only large *Acacia tortilis* trees as protection against sand invasion, and these have not been able to withstand the sand dunes. In some areas there was in January 2004 sand down to the main canal, which runs parallel to the Nile in the middle of the scheme. Thus half of the scheme was not in use. The Abdutab villagers stated that they had watered the prosopis seedlings for two years until the shelterbelts were successfully established.

The above specific interviews provided an opportunity to better understand how the sand invasion and the resettlement decisions are taken in the households. As seen from the above interview results, sand invasion was an important factor when a decision was taken to leave the old village and move to town. However, once the household had emigrated and resettled in a new place, it could be seen as a new page turned in the family members' old lives which thereafter were more linked to the life situation in the resettlement location than to the old village. Because of this fact the families that were leaving from the framed area were not part of the benefit-cost TEV analysis anymore from the moment of resettlement. The analysis therefore only included the loss of the housing property value which the hopuseholds that had left Al Hosh (in 2002 or 2003) had not been able to sell when they left the village.

**ANNEX C**

# TABLES AND FIGURES PRESENTED IN THE STUDY

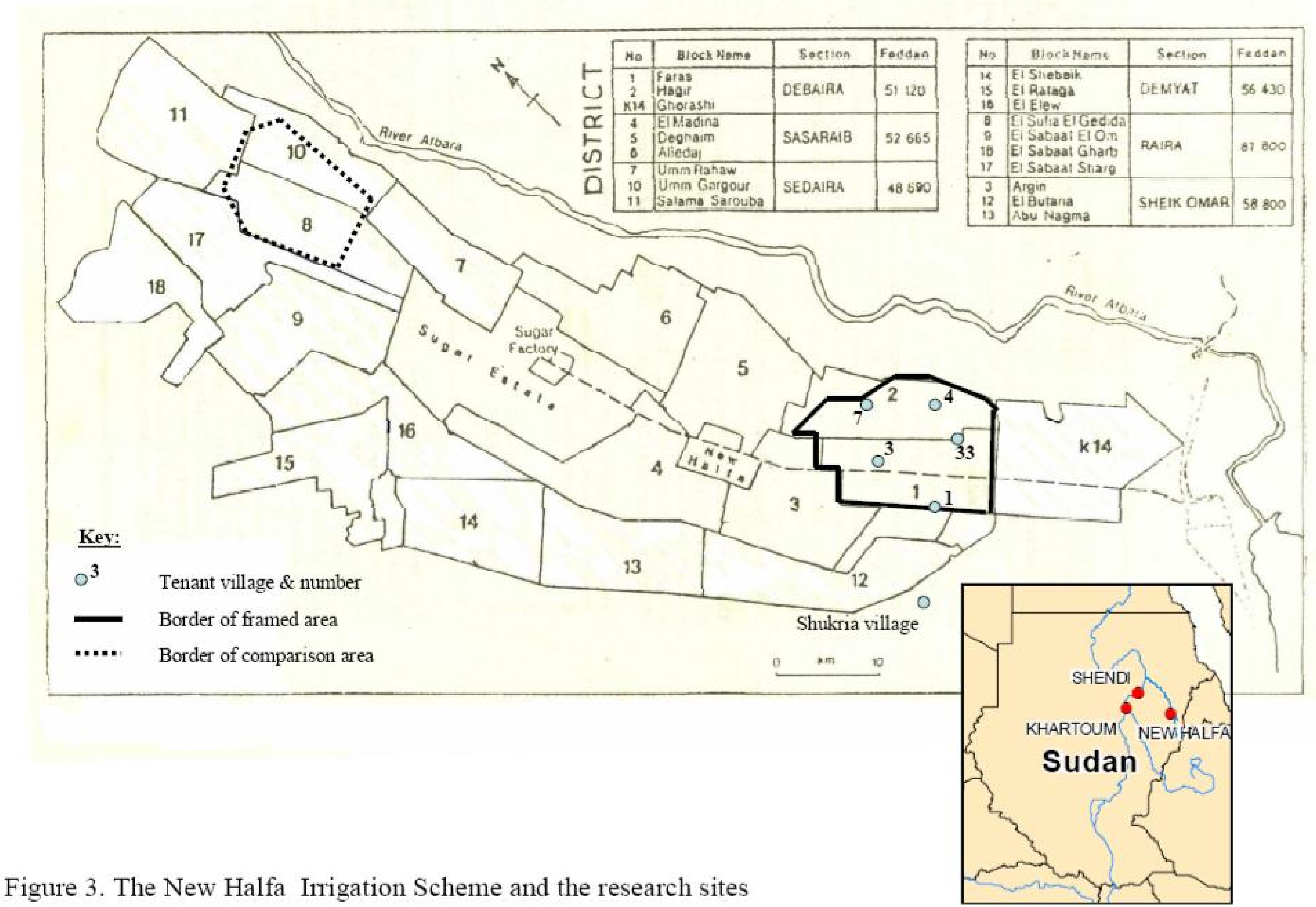
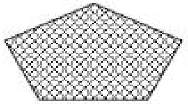
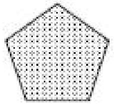



Figure 3. The New Halfa Irrigation Scheme and the research sites

## Key to map on next page:



= Village or part of village



= Part of village that consists of spread-out households

= Boundary of the framed area in Gandato Scheme

= Boundaries of the prosopis bufferzone & fields towards the villages

= Indicates the site for the proposed potential shelterbelt

= Indicates the railway line between Khartoum and Shendi

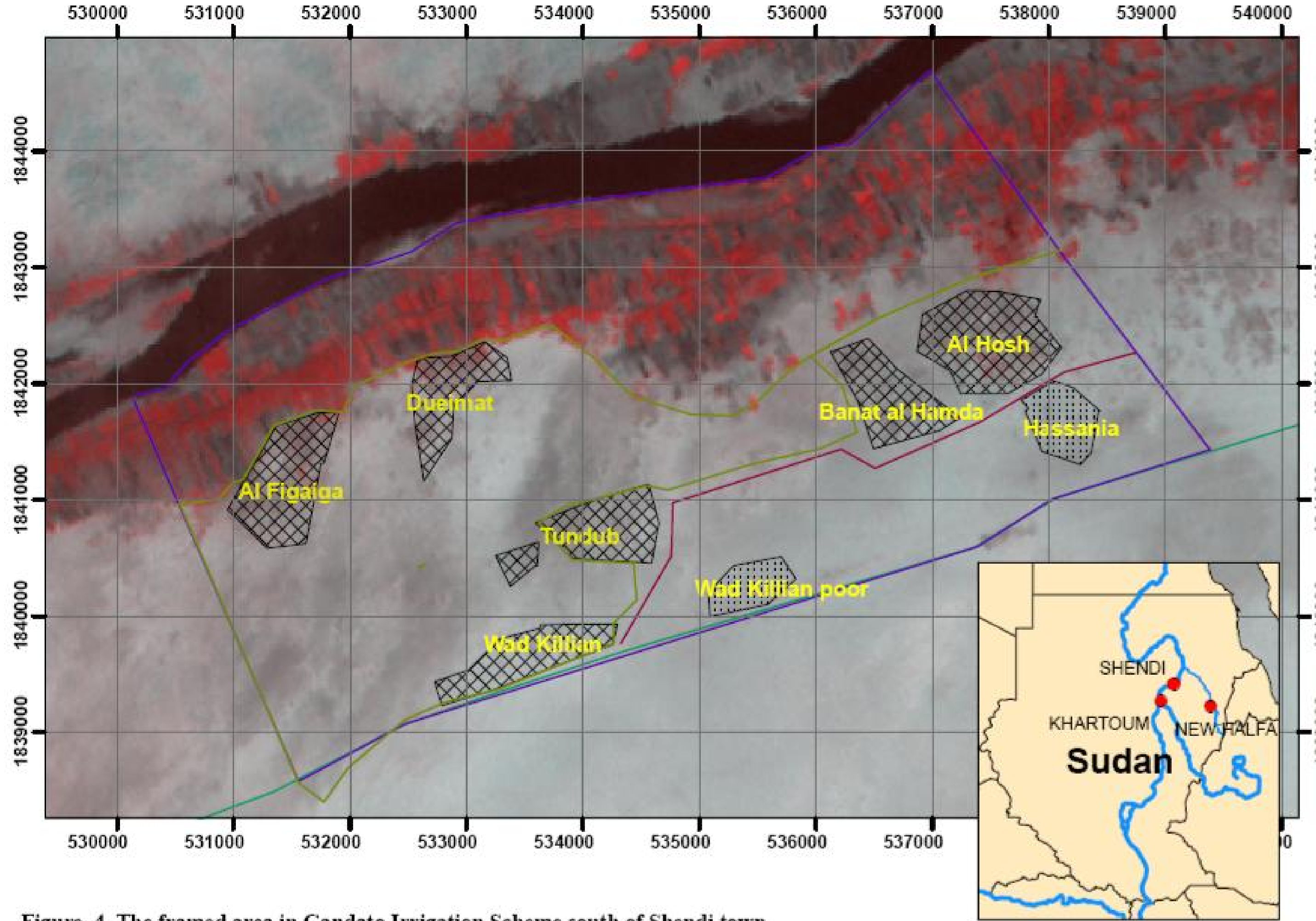



Figure 4. The framed area in Gandato Irrigation Scheme south of Shendi town

Table 1. Structure of New Halfa tenant household economies (in Sudanese Dinars).

| **Household budget item** N= 30 households | **Income quintile** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | | **2** | | **3** | | **4** | | **5** | |
| | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. |
| Crop gross margin | | | | | | | | | | |
| Net cash income from crops | 120821 | 65091 | 221086 | 161319 | 402195 | 247976 | 559891 | 153044 | 737407 | 509909 |
| Net subsistence income from crops | 738 | 6677 | 10683 | 6814 | 8050 | 4114 | 11383 | 3355 | 11533 | 4372 |
| Livestock net income/expenses | | | | | | | | | | |
| Net cash income from livestock | -43067 | 32319 | -49083 | 43044 | -32767 | 43789 | -50550 | 47391 | -45238 | 61719 |
| Net subsistence income | 55688 | 45094 | 67000 | 59258 | 32150 | 39814 | 49075 | 39274 | 96913 | 122987 |
| Net income of labour work | | | | | | | | | | |
| Net income of unskilled labour (excluding prosopis related labour) | 1667 | 4083 | 26000 | 63687 | 0 | 0 | 0 | 0 | 0 | 0 |
| Net income from skilled labour work | 0 | 0 | 30000 | 73485 | 70000 | 171464 | 52000 | 127374 | 50000 | 122475 |
| Net income merchant/transportation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 275567 | 352616 |
| Net remittances (private & pension) | 40000 | 97980 | 20000 | 48990 | 72000 | 139324 | 138000 | 113525 | 40000 | 97980 |
| **Absolute non-environmental cash income** | 119421 | 152548 | 248003 | 67686 | 511345 | 36619 | 699342 | 51555 | 1057736 | 418944 |
| **Absolute non-environmental subsistence income** | 63071 | 49778 | 77683 | 65442 | 40200 | 41211 | 60458 | 37518 | 108446 | 123308 |
| Environmental net income | | | | | | | | | | |
| Prosopis net cash income/expense | -38036 | 118737 | -21778 | 10479 | -24453 | 9656 | -24100 | 10653 | -27150 | 11122 |
| Prosopis net subsistence income | 179261 | 199010 | 233193 | 248791 | 68844 | 91462 | 157574 | 185598 | 197880 | 184487 |
| Other subsistence fodder/forage | 55803 | 62187 | 71141 | 82839 | 16865 | 30488 | 47284 | 61054 | 59198 | 61543 |
| **Absolute cash income** | 81385 | 46226 | 226225 | 63475 | 486975 | 35424 | 675242 | 55211 | 1030586 | 413976 |
| **Absolute subsistence income** | 298134 | 303412 | 382017 | 390354 | 125909 | 162679 | 272316 | 285045 | 365524 | 363290 |
| Total known household costs | -59917 | 19845 | -100283 | 14353 | -113767 | 15095 | -125700 | 9055 | -112800 | 2562 |
| **Absolute net cash income** | 21468 | 34813 | 125933 | 49648 | 373208 | 38457 | 549542 | 55084 | 917786 | 410633 |

Table 2. Socio-economic background of tenant households in New Halfa.

| Household information<br>N= 30 households | Income quintile 1 Mean | s.d. | 2 Mean | s.d. | 3 Mean | s.d. | 4 Mean | s.d. | 5 Mean | s.d. |
|---|---|---|---|---|---|---|---|---|---|---|
| Age of household head (years) | 48.3 | 16 | 49.7 | 11.3 | 51.2 | 9.1 | 58.7 | 9.7 | 37.7 | 6.2 |
| Education level (0,1,2) * of household head | 1.33 | 0.82 | 1.17 | 0.75 | 1.42 | 0.66 | 0.67 | 0.52 | 1.83 | 0.41 |
| Since when in this village | 1960s | | 1960s | | 1960s | | 1960s | | 1960s & birth | |
| Parents origin | Wadi Halfa | | Wadi Halfa | | Wadi Halfa | | Wadi Halfa | | Wadi Halfa | |
| Ethnic background | Nubian | | Nubian | | Nubian | | Nubian | | Nubian | |
| Households distance to highway & main canal (close, medium or remote) | 50% close | | 50% medium | | 1/3 for each distance | | 83% medium | | 67% remote | |
| Amount of scheme land (feddans) | 15 | 0 | 15 | 0 | 15 | 0 | 15 | 0 | 15 | 0 |
| Amount freehold land (feddans) | 7.7 | 9 | 4.08 | 1.63 | 3.3 | 1.86 | 4.33 | 2.34 | 4.17 | 3.25 |
| Household size (members) | 4.83 | 2.32 | 7.83 | 3.43 | 6.33 | 2.88 | 8 | 1.41 | 8.17 | 1.6 |

* Education level: 0 = no education, 1 = primary school, and 2 = secondary school or higher

Table 3. Tenant households' income from environmental resources in New Halfa.
(In Sudanese Dinars)

| Prosopis and other environmental income item | Income quintile 1 Mean | s.d. | 2 Mean | s.d. | 3 Mean | s.d. | 4 Mean | s.d. | 5 Mean | s.d. |
|---|---|---|---|---|---|---|---|---|---|---|
| * Other free-grazing forage | 51303 | 65573 | 71141 | 82839 | 16865 | 30488 | 47284 | 61054 | 59198 | 61543 |
| * Prosopis free-grazing forage | 156594 | 195332 | 213422 | 248516 | 50594 | 91462 | 141850 | 183162 | 177594 | 184628 |
| * Fuelwood (collected) | 21292 | 9424 | 19771 | 3725 | 18250 | 0 | 15208 | 7451 | 19771 | 3725 |
| * Prosopis poles (collected) | 1375 | 2370 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * Crop residues (as fuel) | 4500 | 11023 | 0 | 0 | 0 | 0 | 7000 | 10844 | 0 | 0 |
| * Prosopis fence (installed) | 0 | 0 | 0 | 0 | 0 | 0 | 516 | 1262 | 516 | 1262 |
| * Fuelwood (purchased) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * Charcoal (purchased) | -6600 | 1820 | -6600 | 1004 | -6800 | 980 | -7000 | 2450 | -6000 | 3129 |
| * Prosopis poles (purchased) | -1225 | 1342 | -5400 | 5495 | -3875 | 5908 | -5100 | 5032 | -7817 | 6854 |
| * Prosopis weeding in agri fields | -1778 | 4355 | -9778 | 7851 | -13778 | 7985 | -12000 | 6693 | -13333 | 6532 |
| * Prosopis weeding income | -35000 | 106536 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * Prosopis cutter income | 4167 | 10206 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL in Sudanese Dinars: Prosopis net cash income | -38036 | 118737 | -21778 | 10479 | -24453 | 9656 | -24100 | 10653 | -27150 | 11122 |
| Prosopis subsistence income | 179261 | 199010 | 233193 | 248791 | 68844 | 91462 | 157574 | 185598 | 197880 | 184487 |
| Other subsistence forage income | 55803 | 62187 | 71141 | 82839 | 16865 | 30488 | 47284 | 61054 | 59198 | 61543 |

Table 4. Structure of household economies of western Sudanese landless in New Halfa. (In Sudanese Dinars)

| Household budget item N= 30 households | Income quintile 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. |
| Crop gross margin | | | | | | | | | | |
| Net crop cash gross margin | 25327 | 28013 | 51937 | 57841 | 86057 | 75952 | 68992 | 91930 | 173713 | 275504 |
| Crop subsistence income | 4733 | 4761 | 6350 | 7176 | 9550 | 10857 | 6317 | 7516 | 12167 | 11426 |
| Livestock net income | | | | | | | | | | |
| Net cash income of livestock | -15133 | 20086 | -12000 | 38161 | 85033 | 85670 | 79850 | 92822 | 12867 | 80041 |
| Subsistence income of livestock | 49633 | 42614 | 45817 | 40856 | 88717 | 51427 | 58450 | 56152 | 98283 | 128311 |
| Net income of labour work | | | | | | | | | | |
| Net cash income of unskilled labour (excluding prosopis-related labour) | 15000 | 23238 | 0 | 0 | 22400 | 54869 | 9000 | 22045 | 142500 | 232718 |
| Net income of merchant/manufacture | 3333 | 8165 | 0 | 0 | 9125 | 22352 | 0 | 0 | 359250 | 561893 |
| Remittances (pension): | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8000 | 19596 |
| **Absolute non-environmental cash income** | 28527 | 18370 | 39937 | 44694 | 202615 | 31530 | 157842 | 108861 | 696330 | 426369 |
| **Absolute non-environmental subsistence income** | 54367 | 45239 | 52167 | 44877 | 98267 | 52858 | 64767 | 60995 | 110450 | 137300 |
| Environmental net income | | | | | | | | | | |
| Prosopis net cash income/expense | 32492 | 21655 | 92300 | 44109 | 18542 | 30828 | 174542 | 144428 | 104600 | 235754 |
| Prosopis net subsistence income | 165966 | 85588 | 207262 | 147710 | 406423 | 446213 | 307539 | 332125 | 232860 | 281949 |
| Other subsistence fodder/forage | 33231 | 29509 | 47345 | 49234 | 112181 | 148071 | 82402 | 106315 | 57493 | 92299 |
| **Absolute cash income** | 61018 | 27658 | 132237 | 21339 | 221157 | 33088 | 332383 | 57176 | 800930 | 323504 |
| **Absolute subsistence income** | 253563 | 148345 | 306774 | 233927 | 616871 | 632506 | 454708 | 493865 | 400803 | 508780 |
| Total known household costs | -36400 | 16770 | -72298 | 36214 | -81398 | 31287 | -66766 | 33218 | -79830 | 41635 |
| **Absolute net cash income** | 24618 | 24494 | 59939 | 40662 | 139759 | 57721 | 265618 | 61251 | 721100 | 340635 |

Table 5. Socio-economic background of the western Sudanese landless households in New Halfa.

| **Household information** N= 30 households | **Income quintile** 1 Mean | s.d. | 2 Mean | s.d. | 3 Mean | s.d. | 4 Mean | s.d. | 5 Mean | s.d. |
|---|---|---|---|---|---|---|---|---|---|---|
| Age of household head, years | 50.7 | 11.1 | 40.83 | 4.49 | 44 | 12.8 | 40.5 | 15.1 | 53.3 | 14.49 |
| Education level (0,1,2) * of household head | 0 | 0 | 0.42 | 0.49 | 0.58 | 0.8 | 0.83 | 0.98 | 0.67 | 1.03 |
| Since when in this village | 1970 -80s | | 1970-80s | | Mostly 1980s | | 1980-1990s | | 1960s & 2000s | |
| Parents' origin | Darfur, W Sudan | | Darfur, W Sudan | | W Sudan + Kassala | | W+Central Sudan | | W Sudan + Kassala | |
| Ethnic background | 67% West Sudanian | | 100% West Sudanian | | 67% West Sudanian | | 100% W+C Sudanian | | 67% West Sudanian | |
| Households distance to main canal & highway (Close, medium or remote) | 83% remote | | 67% remote | | 50% close | | 50% close | | 83% close | |
| Amount of shared scheme or freehold land (feddans) | 5 | 5.48 | 5.33 | 4.55 | 5 | 3.16 | 5.83 | 5.85 | 3.83 | 3.19 |
| Household size (members) | 10.5 | 3.62 | 9.83 | 3.37 | 11 | 4.65 | 7.5 | 3.21 | 10.17 | 2.93 |

* Education level: 0 = no education, 1 = primary school, and 2 = secondary school or higher

Table 6. Western Sudanese landless households' income from environmental resources in New Halfa.
(In Sudanese Dinars)

| **Prosopis and other environmental income item** | **Income quintile** 1 Mean | s.d. | 2 Mean | s.d. | 3 Mean | s.d. | 4 Mean | s.d. | 5 Mean | s.d. |
|---|---|---|---|---|---|---|---|---|---|---|
| * Other free-grazing forage | 33231 | 29509 | 47345 | 49234 | 112181 | 148071 | 82402 | 106315 | 57493 | 92299 |
| * Prosopis free-grazing forage | 99692 | 88528 | 142035 | 147703 | 336544 | 444213 | 247206 | 318945 | 172478 | 276897 |
| * Fuelwood (collected) | 39542 | 17943 | 39542 | 13738 | 51708 | 7451 | 41063 | 21400 | 47046 | 18579 |
| * Prosopis poles (collected) | 16417 | 3608 | 13383 | 4699 | 12958 | 1978 | 12458 | 6677 | 11500 | 6950 |
| * Prosopis fence (installed) | 1515 | 1369 | 2303 | 1393 | 1212 | 1484 | 1212 | 1484 | 303 | 742 |
| * Use of own produced charcoal | 8800 | 5402 | 10000 | 2360 | 4000 | 4469 | 5600 | 5402 | 1533 | 3379 |
| * Charcoal (purchased) | -800 | 1960 | 0 | 0 | -3000 | 7349 | -800 | 1960 | -1633 | 2531 |
| * Prosopis cutting as labour | 18292 | 12090 | 64800 | 56795 | 14875 | 28541 | 116175 | 88209 | 77733 | 190015 |
| * Prosopis weeding income | 15000 | 9487 | 27500 | 19937 | 6667 | 7528 | 59167 | 90134 | 28500 | 45161 |
| TOTAL in Sudanese Dinars: Prosopis net cash income | 32492 | 21655 | 92300 | 44109 | 18542 | 30828 | 174542 | 144428 | 104600 | 235754 |
| Prosopis subsistence income | 165966 | 85588 | 207262 | 147710 | 406423 | 446213 | 307539 | 332125 | 232860 | 281949 |
| Other subsistence forage income | 33231 | 29509 | 47345 | 49234 | 112181 | 148071 | 82402 | 106315 | 57493 | 92299 |

Table 7. Structure of household economies of the eastern Sudanese landless in New Halfa.
(In Sudanese Dinars)

| Household budget item | Income quintile | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | |
| N= 30 households | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. |
| Crop gross margin | | | | | | | | | | |
| Net crop cash gross margin | 8033 | 8847 | 9750 | 17005 | 14658 | 22910 | 78733 | 68470 | 111904 | 136018 |
| Crop subsistence income | 3333 | 4083 | 1300 | 2131 | 5633 | 6325 | 10033 | 7657 | 10750 | 5049 |
| Livestock net income | | | | | | | | | | |
| Net cash income of livestock | 1217 | 21790 | -7208 | 11282 | -1033 | 28021 | 29600 | 51651 | 60992 | 139820 |
| Subsistence income of livestock | 56517 | 52620 | 52483 | 41241 | 69867 | 56027 | 54683 | 53467 | 79883 | 51572 |
| Net income of labour work | | | | | | | | | | |
| Net cash income of unskilled labour (excluding prosopis related labour) | 16900 | 21668 | 50867 | 26829 | 63367 | 44494 | 28200 | 49441 | 16500 | 40417 |
| Net Income from skilled labour work | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 52000 | 127374 |
| Net Income of merchant/manufacture | 0 | 0 | 0 | 0 | 17583 | 43070 | 20875 | 51133 | 17833 | 43683 |
| Net remittances: (private & pension) | 0 | 0 | 6667 | 16330 | 0 | 0 | 30000 | 50200 | 6667 | 16330 |
| **Absolute non-environmental cash income** | 26150 | 34145 | 60075 | 13045 | 94575 | 31030 | 187408 | 30514 | 265896 | 23671 |
| **Absolute non-environmental subsistence income** | 59850 | 53517 | 53783 | 41657 | 75467 | 59120 | 64717 | 58010 | 90633 | 53927 |
| Environmental net income | | | | | | | | | | |
| Prosopis net cash income/expense | 18450 | 22457 | 6900 | 10792 | 179 | 16711 | -9242 | 9185 | -9200 | 14488 |
| Prosopis net subsistence income | 211083 | 227934 | 242026 | 120602 | 374987 | 291453 | 342220 | 316920 | 522185 | 460719 |
| Other subsistence fodder / forage | 49240 | 75743 | 59850 | 39916 | 103306 | 94616 | 93964 | 103638 | 153607 | 161694 |
| **Absolute cash income** | 44600 | 12446 | 66975 | 6732 | 94754 | 21853 | 178167 | 27521 | 256696 | 18077 |
| **Absolute subsistence income** | 320173 | 348798 | 355659 | 175927 | 553794 | 423363 | 500900 | 474563 | 766425 | 659328 |
| Total known household costs | -14733 | 8727 | -26717 | 21046 | -32550 | 25781 | -60033 | 39476 | -61867 | 41775 |
| **Absolute net cash income** | 29867 | 10902 | 40258 | 22690 | 62204 | 31601 | 118133 | 34533 | 194829 | 44573 |

Table 8. Socio-economic background of the eastern Sudanese landless households in New Halfa.

| **Household information** N= 30 households | **Income quintile** 1 Mean | s.d. | 2 Mean | s.d. | 3 Mean | s.d. | 4 Mean | s.d. | 5 Mean | s.d. |
|---|---|---|---|---|---|---|---|---|---|---|
| Age of household head (years) | 49.5 | 13.6 | 40 | 13.97 | 48.5 | 15.97 | 46.8 | 24 | 42.5 | 14.4 |
| Education level (0,1,2) * of household head | 0.5 | 0.55 | 0.33 | 0.82 | 0.17 | 0.41 | 0.17 | 0.41 | 1.33 | 0.82 |
| Since when in this village | 1960s | | 1960 - 70s | | 1960s | | 1960s & 1990s | | 1960s & 1990s | |
| Parents origin | Kassala State | | Kassala State | | Kassala State | | Kassala State | | Kassala State | |
| Ethnic background | Local ethnicity | | Local ethnicity | | Local ethnicity | | Local ethnicity | | Local ethnicity | |
| Households distance to highway & main canal (Close or remote) | 83% close | | 83% close | | 83% close | | 83% close | | 67% remote | |
| Amount of shared scheme or freehold land (feddans) | 4.17 | 5.85 | 1.67 | 2.58 | 5.83 | 7.36 | 8.75 | 4.79 | 5 | 0 |
| Land outside scheme (feddans) | 0 | 0 | 0 | 0 | 1.67 | 4.08 | 6.67 | 10.8 | 5.83 | 10.21 |
| Household size (members) | 6.83 | 2.04 | 5.83 | 2.04 | 7.5 | 0.55 | 9 | 5.59 | 6.92 | 2.38 |

* Education level: 0 = no education, 1 = primary school, and 2 = secondary school or higher

Table 9. Eastern Sudanese landless households' income from environmental resources in New Halfa.
(In Sudanese Dinars)

| **Prosopis and other environmental income item** | **Income quintile** 1 Mean | s.d. | 2 Mean | s.d. | 3 Mean | s.d. | 4 Mean | s.d. | 5 Mean | s.d. |
|---|---|---|---|---|---|---|---|---|---|---|
| * Other free-grazing forage | 49240 | 75743 | 59850 | 39916 | 103306 | 94616 | 93964 | 103638 | 153607 | 161694 |
| * Prosopis free-grazing forage | 147719 | 227230 | 179550 | 119748 | 309919 | 283848 | 281891 | 310913 | 460819 | 485082 |
| * Fuelwood (collected) | 57500 | 7110 | 57500 | 7110 | 59313 | 11176 | 58938 | 11365 | 59388 | 31583 |
| * Prosopis poles (collected) | 4458 | 3387 | 4067 | 3297 | 4350 | 4501 | 1392 | 2226 | 1675 | 2595 |
| * Use of charcoal | 800 | 1960 | 0 | 0 | 800 | 1960 | 0 | 0 | 0 | 0 |
| * Prosopis fence (installed) | 606 | 939 | 909 | 996 | 606 | 939 | 0 | 0 | 303 | 742 |
| * Prosopis cutting as labour | 17050 | 22561 | 8333 | 10764 | 5000 | 12247 | 0 | 0 | 0 | 0 |
| * Prosopis weeding income | 4000 | 4382 | 2667 | 4132 | 2500 | 3886 | 8000 | 10119 | 3000 | 7746 |
| * Fuelwood (purchased) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * Charcoal (purchased) | -2600 | 4099 | -4100 | 4576 | -5721 | 4489 | -10842 | 2677 | -5800 | 5058 |
| * Prosopis poles (purchased) | 0 | 0 | 0 | 0 | -1600 | 3919 | -6400 | 4957 | -6400 | 4957 |
| TOTAL in Sudanese Dinars: Prosopis net cash income | 18450 | 22457 | 6900 | 10792 | 179 | 16711 | -9242 | 9185 | -9200 | 14488 |
| Prosopis subsistence income | 211083 | 227934 | 242026 | 120602 | 374987 | 291453 | 342220 | 316920 | 522185 | 460719 |
| Other subsistence forage income | 49240 | 75743 | 59850 | 39916 | 103306 | 94616 | 93964 | 103638 | 153607 | 161694 |

Table 10. Structure of household economies of nomads in New Halfa (in Sudanese Dinars).

| **Household budget item** | **Income quintile** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | | **2** | | **3** | | **4** | | **5** | |
| N= 20 households | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. |
| Crop gross margin | | | | | | | | | | |
| Net crop cash gross margin | 22000 | 0 | 28650 | 13300 | 23175 | 3450 | 22000 | 0 | 18225 | 12578 |
| Crop subsistence income | 0 | 0 | 2175 | 4350 | 0 | 0 | 0 | 0 | 0 | 0 |
| Livestock net income | | | | | | | | | | |
| Net cash income of livestock | -10125 | 8606 | -35750 | 64690 | -97375 | 112571 | -105800 | 564359 | 121513 | 247358 |
| Subsistence income of livestock | 12656 | 11151 | 32063 | 59710 | 115313 | 9915 | 77175 | 56913 | 104625 | 75518 |
| Net income of labour work | | | | | | | | | | |
| Net cash income of unskilled labour (excluding prosopis related labour) | 13125 | 26250 | 57750 | 93061 | 290250 | 95330 | 309375 | 445619 | 146250 | 125872 |
| Net Income of merchant/manufacture | 7500 | 15000 | 3000 | 6000 | 0 | 0 | 0 | 0 | 0 | 0 |
| Net remittances: (private & pension) | 16200 | 18936 | 26250 | 39752 | 5250 | 10500 | 63000 | 126000 | 250625 | 353780 |
| **Absolute non-environmental cash income** | 48700 | 5260 | 79900 | 33289 | 221850 | 32943 | 288575 | 8428 | 536613 | 252305 |
| **Absolute non-environmental subsistence income** | 12656 | 11151 | 34238 | 64054 | 115313 | 9915 | 77175 | 56913 | 104625 | 75518 |
| Environmental net income | | | | | | | | | | |
| Prosopis net cash income/expense | -2625 | 1750 | 3375 | 6909 | -3938 | 2989 | -9800 | 3960 | -2188 | 2625 |
| Prosopis net subsistence income | 91298 | 65970 | 104948 | 135912 | 674340 | 148431 | 4425951 | 5689805 | 590648 | 543706 |
| Other subsistence fodder / forage | 15278 | 14721 | 18690 | 34637 | 160710 | 36906 | 1253949 | 1333347 | 138303 | 133427 |
| **Absolute cash income** | 46075 | 3824 | 83275 | 35465 | 217913 | 30656 | 283675 | 8507 | 534425 | 252870 |
| **Absolute subsistence income** | 119231 | 91733 | 157875 | 234526 | 950363 | 180366 | 5757075 | 7052510 | 833575 | 744931 |
| Total known household costs | -36000 | 0 | -45500 | 19000 | -51750 | 4500 | -87200 | 27054 | -133200 | 83662 |
| **Absolute net cash income** | 10075 | 3824 | 37775 | 24438 | 166163 | 29070 | 196475 | 29951 | 401225 | 235651 |

Table 11. Socio-economic background of nomad/semi-nomad households in New Halfa.

| **Household information** N= 20 households | **Income quintile** 1 Mean | s.d. | 2 Mean | s.d. | 3 Mean | s.d. | 4 Mean | s.d. | 5 Mean | s.d. |
|---|---|---|---|---|---|---|---|---|---|---|
| Age of household head (years) | 40.2 | 18.3 | 52.5 | 16.6 | 53.8 | 11.8 | 34.8 | 13.5 | 42.8 | 12.9 |
| Education level (0,1,2) * of household head | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 1 |
| Since when in this village | Migrating annually | | Migrating annually | | Migrating annually | | Migrate & - semi-settled | | Migrating annually | |
| Annual duration in Scheme | November-June (7 months) | | November-June (7 months) | | November-June (7 months) | | November-June (7 months) | | November-June (7 months) | |
| Parents origin | Kassala State | | Kassala State | | Kassala State | | Kassala State | | Kassala State | |
| Ethnic background | Rashaida | | Rashaida | | Rashaida | | Rashaida & Bewadra | | Rashaida | |
| Camp distance to highway & main canal (close or remote) | Close | | Close | | Close | | Close/ Remote | | Close | |
| Amount of rainfed or scheme land | rainfed ca 5 feddan | | rainfed ca 5 feddan | | rainfed ca 5 feddan | | rainfed ca 5 feddan | | Rainfed 5 feddan (1 hh had 5 feddan shared schemeland) | |
| Household size | 6.75 | 2.06 | 7.25 | 2.22 | 9.75 | 2.06 | 8.5 | 4.36 | 12.62 | 8.44 |

* Education level: 0 = no education, 1 = primary school, and 2 = secondary school or higher

Table 12. Nomad/Semi-Nomadic households' income from environmental resources in New Halfa.
(In Sudanese Dinars)

| **Prosopis and other environmental income item** | **Income quintile** 1 Mean | s.d. | 2 Mean | s.d. | 3 Mean | s.d. | 4 Mean | s.d. | 5 Mean | s.d. |
|---|---|---|---|---|---|---|---|---|---|---|
| * Other free-grazing forage | 15278 | 14721 | 18690 | 34637 | 160710 | 36906 | 1253949 | 1333347 | 138303 | 133427 |
| * Prosopis free-grazing forage | 61110 | 58885 | 74760 | 138547 | 642840 | 147626 | 4406264 | 5682189 | 555210 | 53897 |
| * Fuelwood (collected) | 30188 | 7875 | 30188 | 7875 | 31500 | 7425 | 19688 | 10823 | 35438 | 7875 |
| * Prosopis poles (collected) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * Fuelwood (purchased) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * Charcoal (purchased) | -2625 | 1750 | -2625 | 1750 | -3938 | 2989 | -9800 | 3960 | -2188 | 2625 |
| * Prosopis poles (purchased) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * Prosopis weeding labour | 0 | 0 | 6000 | 7659 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL in Sudanese Dinars | | | | | | | | | | |
| Prosopis net cash income | -2625 | 1750 | 3375 | 6909 | -3938 | 2989 | -9800 | 3960 | -2188 | 2625 |
| Prosopis subsistence income | 91298 | 65970 | 104948 | 135912 | 674340 | 148431 | 4425951 | 5689805 | 590648 | 543706 |
| Other subsistence income | 15278 | 14721 | 18690 | 34637 | 160710 | 36906 | 1253949 | 1333347 | 138303 | 133427 |

Table 13. Relative share of prosopis and other environmental incomes from the households' absolute total income (mean AI in SD and other figures as decimal ratios).

| Population group | Absolute Total Income Quintiles | | | | | Mean for all HHs | Mean for all HHs/forage non-inter-nalized |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | |
| **Tenants/ New Halfa:** | | | | | | | |
| Mean AI (SD) | 164,183 | 408,274 | 558,130 | 775,589 | 1,241,165 | 629,468 | 788,862 |
| RCI = ACI/ AI | 0.67 | 0.56 | 0.86 | 0.86 | 0.82 | 0.79 | 0.63 |
| RCFI = (ACFIprosopis/AI) | 0.01 | -0.04 | -0.05 | -0.03 | -0.02 | -0.03 | -0.03 |
| RFI = AFI/ AI | 0.35 | 0.31 | 0.07 | 0.09 | 0.13 | 0.14 | 0.24 |
| RFIp = (AFIprosopis/AI) | 0.18 | 0.11 | 0.01 | 0.02 | 0.05 | 0.05 | 0.18 |
| RSFIp=(ASFIprosopis/AI) | 0.17 | 0.16 | 0.06 | 0.05 | 0.07 | 0.08 | 0.21 |
| RSFIoth=(ASFIother/AI) | 0.18 | 0.2 | 0.07 | 0.06 | 0.08 | 0.09 | 0.06 |
| **W. Sud. Landless/New Halfa:** | | | | | | | |
| Mean AI (SD) | 171,062 | 312,053 | 415,317 | 577,066 | 1,047,186 | 504,537 | 716,089 |
| RCI | 0.42 | 0.53 | 0.55 | 0.49 | 0.76 | 0.61 | 0.43 |
| RCFI | 0.28 | 0.31 | 0.59 | 0.1 | 0.1 | 0.17 | 0.12 |
| RFI | 1.17 | 0.92 | 0.79 | 0.64 | 0.34 | 0.61 | 0.58 |
| RFIp | 0.71 | 0.61 | 0.52 | 0.34 | 0.21 | 0.37 | 0.49 |
| RSFIp | 0.44 | 0.49 | 0.24 | 0.24 | 0.11 | 0.21 | 0.37 |
| RSFIoth | 0.45 | 0.52 | 0.27 | 0.29 | 0.13 | 0.24 | 0.09 |
| **E. Sud. Landless/ New Halfa:** | | | | | | | |
| Mean AI (SD) | 141,790 | 347,491 | 629,408 | 967,078 | 1,513,667 | 719,886 | 627,629 |
| RCI | 0.39 | 0.43 | 0.15 | 0.16 | 0.11 | 0.17 | 0.2 |
| RCFI | 0.14 | 0 | 0.02 | -0.01 | 0 | 0 | 0 |
| RFI | 1.04 | 0.83 | 1.34 | 1.26 | 1.42 | 1.29 | 0.69 |
| RFIp | 0.56 | 0.33 | 0.59 | 0.54 | 0.61 | 0.56 | 0.54 |
| RSFIp | 0.41 | 0.33 | 0.59 | 0.55 | 0.62 | 0.56 | 0.54 |
| RSFIoth | 0.49 | 0.5 | 0.75 | 0.72 | 0.81 | 0.73 | 0.15 |
| **Nomads/ New Halfa:** | | | | | | | |
| Mean AI (SD) | 87,486 | 175,235 | 397,098 | 515,521 | 786,541 | 392,376 | 1,796,696 |
| RCI | 0.59 | 0.67 | 0.51 | 0.52 | 0.67 | 0.59 | 0.13 |
| RCFI | -0.01 | -0.01 | 0 | -0.01 | -0.01 | -0.01 | 0 |
| RFI | 0.75 | 0.44 | 0.48 | 0.47 | 0.33 | 0.43 | 0.83 |
| RFIp | 0.37 | 0.2 | 0.22 | 0.21 | 0.15 | 0.19 | 0.65 |
| RSFIp | 0.37 | 0.21 | 0.22 | 0.22 | 0.16 | 0.2 | 0.66 |
| RSFIoth | 0.38 | 0.23 | 0.26 | 0.26 | 0.18 | 0.23 | 0.18 |
| **All population/New Halfa:** | | | | | | | |
| Mean AI (SD) | 133,535 | 319,654 | 486,063 | 693,769 | 1,251,719 | 576,948 | 908,285 |
| RCI | 0.48 | 0.54 | 0.55 | 0.6 | 0.45 | 0.52 | 0.33 |
| RCFI | 0.09 | 0.11 | 0.04 | 0.05 | -0.01 | 0.03 | 0.02 |
| RFI | 0.85 | 0.67 | 0.54 | 0.56 | 0.79 | 0.68 | 0.61 |
| RFIp | 0.44 | 0.4 | 0.28 | 0.31 | 0.38 | 0.38 | 0.48 |
| RSFIp | 0.36 | 0.25 | 0.23 | 0.23 | 0.35 | 0.29 | 0.47 |
| RSFIoth | 0.41 | 0.27 | 0.26 | 0.24 | 0.35 | 0.3 | 0.13 |
| **All population/ Gandato:** | | | | | | | |
| Mean AI (SD) | 122,266 | 213,774 | 411,050 | 787,871 | 1,881,657 | 683,323 | 1,005,772 |
| RCI | 0.5 | 0.66 | 0.56 | 0.71 | 0.77 | 0.72 | 0.49 |
| RCFI | -0.1 | -0.07 | -0.08 | -0.03 | -0.02 | -0.04 | -0.02 |
| RFI | 0.21 | 0.08 | 0.08 | 0.11 | 0.09 | 0.1 | 0.41 |
| RFIp | 0.18 | 0.05 | 0.04 | 0.07 | 0.03 | 0.05 | 0.2 |
| RSFIp | 0.28 | 0.12 | 0.12 | 0.09 | 0.06 | 0.08 | 0.22 |
| RSFIoth | 0.03 | 0.04 | 0.04 | 0.04 | 0.06 | 0.05 | 0.19 |

Table 14. New Halfa Framed Area villages' utilization of prosopis for fencing, bakery fuelwood and vehicle puncture expenses.

| **Village/Camp name** | **Houses/ huts = House-holds** | **No. of huts with prosopis fence in camp** | **Length of fence around yard,** (m) | **Length of all prosopis hut/field fences** (m) | **Fence as barb wire subsititute** | **Bakery fuelwood consump.** | **Puncture cars** | **Puncture lorry/ truck** | **Puncture Tractor** |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | In Sudanese Dinars | | | | |
| Block 1 staff | 22 | | | 1,500 | 272,727 | | | | |
| Village 3 tenants | 175 | | | 800 | 145,455 | 182,500 | -912,500 | -600,000 | -1,500,000 |
| Village 33 tenants | 250 | | | 600 | 109,091 | 182,500 | -164,250 | -4,500 | -390,000 |
| Village 1 tenants | 350 | 2 | 50 | 4,500 | 836,364 | 182,500 | -164,250 | -4,500 | -390,000 |
| Block 2 staff | 22 | | | 1,500 | 272,727 | | | | |
| Village 4 tenants | 240 | | | | | 182,500 | -146,000 | | |
| Village 7 tenants | 225 | | | | | 182,500 | -438,000 | -180,000 | -300,000 |
| Cadisia mixed - landless camp | 212 | 35 | 50 | 1,750 | 318,182 | | | | |
| V7 ES landless | 80 | 80 | 50 | 4,000 | 727,273 | | | | |
| V7 WS landless | 200 | 56 | 50 | 2,800 | 509,091 | | | | |
| V4 WS landless | 30 | 21 | 50 | 1,050 | 190,909 | | | | |
| V33 WS landless | 50 | 28 | 50 | 1,400 | 254,545 | | | | |
| V33 WS/ES - mixed landless | 145 | 9 | 50 | 450 | 81,818 | | | | |
| Kimilab ES camp | 74 | | | | | | | | |
| V1 WS landless | 167 | | | | | | | | |
| | | | | | Total in Sudanese Dinars | | | | |
| **Total** | 2,242 | 231 | | 20,350 | 3,718,182 | 912,500 | -1,825,000 | -789,000 | -2,580,000 |

Table 15. Estimated charcoal production and trade in June 2002 – June 2003 for the framed research area in New Halfa Scheme.

| **Village/Camp** | **Charcoal used in producer village** (in sacks) | **Value of charcoal used by producers in camps** Sudanese Dinars | **Charcoal sold in camps or adjacent villages** (in sacks) | **Value of charcoal sold in camp or nearby village** Sudanese Dinars | **Charcoal sold to merchant inside the area** (in sacks) | **Charcoal sold outside area by merchants** (in sacks) | **Value of charcoal sacks pur-chased & resold out from area** | **Charcoal tax income to State** Sudanese Dinars | **Charcoal transport & trade gross income** Sudanese Dinars | **Total amount of charcoal produced in -02/03 in the framed area** (in sacks) |
|---|---|---|---|---|---|---|---|---|---|---|
| Block 1 staff | 0 | 0 | not known | not known | | | | | | |
| Village 3 tenants 175 | 0 | 0 | 1,800 | 900,000 | | 21,600 | 10,800,000 | 4,320,000 | 10,800,000 | 1,800 |
| Village 33 tenants 250 | 0 | 0 | 3,600 | 2,160,000 | | 5,700 | 2,850,000 | 1,140,000 | 2,850,000 | 3,600 |
| Village 1 tenants 350 | 0 | 0 | 1,800 | 900,000 | 3,650 | | | | | 5,450 |
| Block 2 staff | 0 | 0 | not known | not known | 0 | | | | | |
| Village 4 tenants 240 | 0 | 0 | 600 | 300,000 | 5,400 | | | | | 6,000 |
| Village 7 tenants 225 | 0 | 0 | 2,400 | 1,200,000 | 600 | | | | | 3,000 |
| Cadisia WS/ES landless | 3,516 | 1,406,400 | 0 | 0 | 2,040 | | | | | 5,556 |
| V7 ES landless | 360 | 144,000 | 660 | 264,000 | 0 | | | | | 1,020 |
| V4 ES landless | 20 | 8,000 | 660 | 264,000 | 0 | | | | | 680 |
| V7 WS landless | 4,368 | 1,747,200 | 0 | 0 | 8,100 | | | | | 12,468 |
| V4 WS landless | 655 | 262,080 | 0 | 0 | 3,000 | | | | | 3,655 |
| V33 WS landless | 1,092 | 436,800 | 0 | 0 | 560 | | | | | 1,652 |
| V33 Kimilab landless | 0 | 0 | 1,159 | 637,560 | 1,800 | | | | | 2,959 |
| Majasid ES landless | 0 | 0 | 1,224 | 673,200 | 0 | | | | | 1,224 |
| V1 WS landless | 321 | 128,352 | 0 | 0 | 660 | | | | | 981 |
| Prosopis cutter group 1 | 12 | 4,800 | 0 | 0 | 560 | | | | | 572 |
| Prosopis cutter group 2 | 12 | 4,800 | 0 | 0 | 800 | | | | | 812 |
| *Estimation discrepancy between production and merchant trade* | | | | | *130* | | | | | |
| **Total in S. Dinars (in bold)** | *10,356* | **4,142,432** | *13,903* | **7,298,760** | *27,300* | *27,300* | **13,650,000** | **5,460,000** | **13,650,000** | *51,429* |

Table 16. Comparison between southern and northern areas of the New Halfa Irrigation Scheme.

| Villages in southern framed research area - prosopis | Villages in northern scheme parts – no prosopis |
|---|---|
| 1. Prosopis has invaded the area since about 1990; | 1. Whole area bare of trees except some village eucalypts and neem trees; |
| 2. Tenant farmers are Nubians originating from Wadi Halfa (Northern State) – each family has got 15 feddan of schemeland; | 2. Small-scale tenants from Kassala State or from Western Sudan cultivating 5 feddan of schemeland; |
| 3. A few thousand landless households live in the scheme – most have no official scheme income; | 3. A few thousand landless households live in the area & many labour in the scheme or in the sugar factory; |
| 4. Some one hundred nomad households live in the scheme area south of New Halfa in dry season; | 4. No nomads live in the northern parts of the scheme; |
| 5. Nubian tenant farmers have got freehold land (0 - 25 feddan) based on the amount of land they had owned in Wadi Halfa. Crops could be grown at own choice; | 5. Tenant farmers have mostly schemelands, but some have also a few feddans of freehold land on which any crop can be grown; |
| 6. On schemeland rotated cotton, sorghum and groundnut mostly in a three-year single annual rotation; | 6. On schemeland rotated cotton, sorghum and groundnut mostly in a three-year single annual rotation; |
| 7. Tenants have lower income/ less cultivated schemeland due to prosopis invasion; | 7. Tenants have higher income/ less cultivated schemeland at least partly due to no disturbing prosopis; |
| 8. Prosopis-related operational expenses are reducing income for tenants; | 8. No prosopis-related expenses yet (although small pockets of prosopis already exist at a few sites); |
| 9. Landless population can rent or share 5 – 15 feddan of schemeland or freehold land from tenants more easily due to prosopis invasion; | 9. Landless population can sometimes rent or share schemeland or freehold land from tenants; |
| 10. Landless population has more diversified income sources due to prosopis; | 10. Landless population has few income sources besides scheme field labour work; |
| 11. Daily salary for labour work varies between 400 – 650 dinars/day (more money in circulation); | 11. Daily salary for labour work is normally 300 – 350 dinars/ day (less money in circulation); |
| 12. Prosopis gives many steady work opportunities with immediate cash payments; | 12. No wood-based income in the area; |
| 13. Energy can be covered free of charge; | 13. Energy costs are high – everything needs to be bought; |
| 14. Poorer households mostly used own charcoal and firewood or purchase them at cheap price; | 14. Poor households mostly used secondary fuels such as agricultural residues; |
| 15. Tenant farmers also purchased costly liquid gas; | 15. Tenants also purchase costly liquid gas and charcoal; |
| 16. Livestock less expensive to keep due to free-grazing forage; | 16. Livestock only feed on cultivated fodder, which is expensive; |
| 17. Livestock can be sold in cash crisis situations; | 17. Few livestock to sell in cash crisis situations; |
| 18. Landless can sometimes be richer than tenant farmers – variable income sources and lower living costs; | 18. Landless population appears extremely poor – smaller salary and higher living costs; |
| 19. Everybody suffers from monthly malaria (or similar disease) in this area; | 19. Each month some 40% of population is ill from malaria in this area; |
| 20. All have chronic schistosomiasis from the main canal; | 20. All have chronic schistosomiasis from the main canal; |
| 21. Severe thorn injuries from prosopis occur frequently; | 21. No thorn injuries from prosopis; |
| 22. Health costs are 1,000-2,000 Dinars higher per medical visit in the southern parts; | 22. Health costs are lower per medical visit in the northern parts; |
| 23. Landless children had better education opportunities. | 23. Landless children had few education opportunities and there is severe and apathic poverty in some villages. |

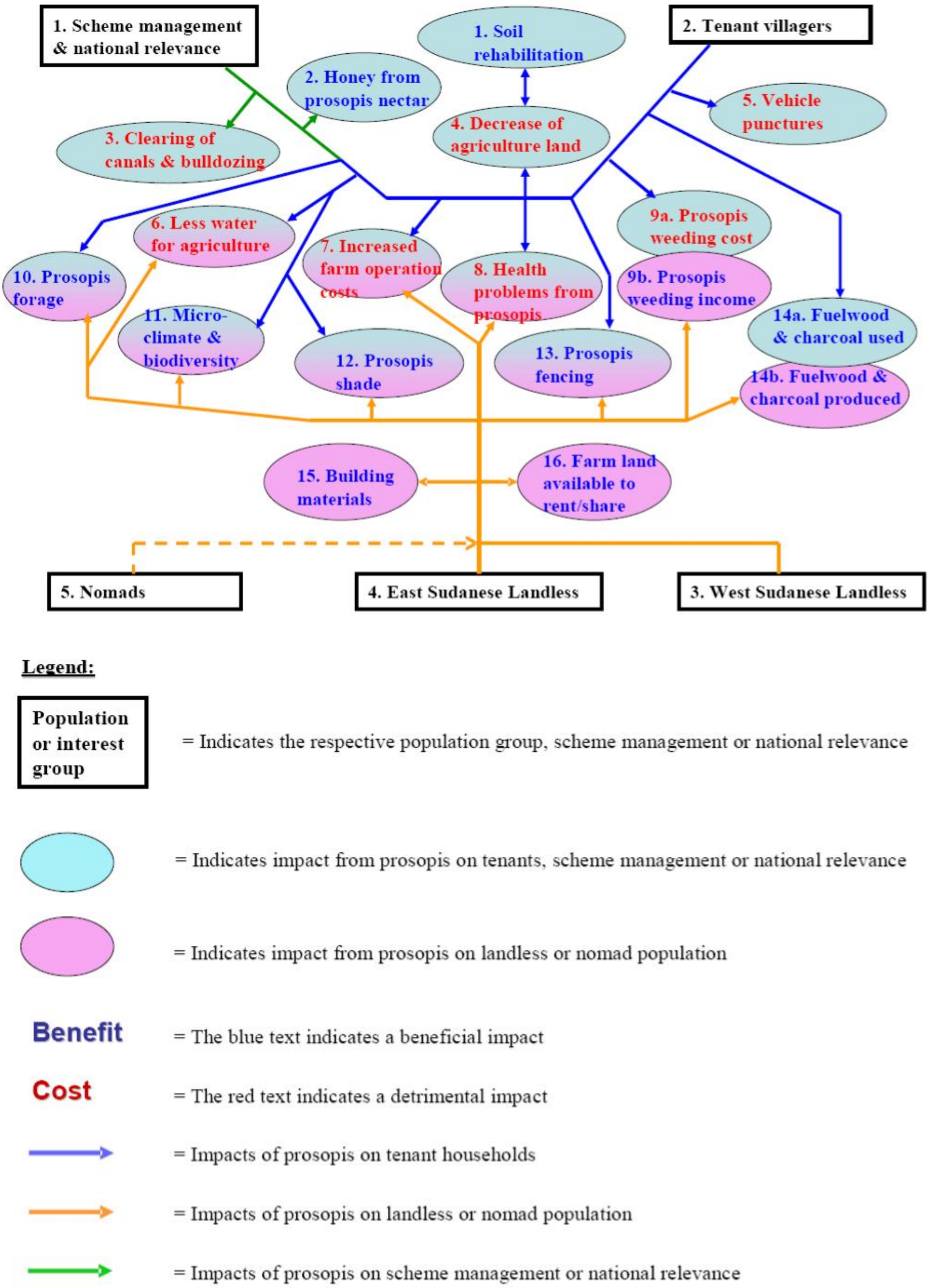



Figure 6. Impact of prosopis on each respective population group in the framed research area of the New Halfa Irrigation Scheme.

Table 17. Magnitudes of prosopis impacts in the framed area of New Halfa Scheme in 2002 – 2003.

| **Item** | **Tenants** | **W. Sud. Landl.** | **E. Sud. Landl.** | **Total all Groups** | **Each benefit or cost in % of over-all total** |
|---|---|---|---|---|---|
| Household No. | 1240 | 585 | 345 | 2170 | |
| **Item** | **Household Mean** | **Household Mean** | **Household Mean** | **Benefit Total** | |
| | Sudanese Dinars | Sudanese Dinars | Sudanese Dinars | Sudanese Dinars | |
| **BENEFITS** | | | | | |
| Prosopis forage | | | | | |
| Prosopis forage[a] | 148,011 | 199,591 | 275,980 | 395,507,475 | n.a. |
| Fodder efficiency in % of total fodder[b] | 29.25% | 41.77% | 24.75% | 31.50% | |
| Prosopis forage[c] | 43,293 | 83,369 | 68,305 | 124,584,855 | 43.89% |
| Prosopis production and trade income | | | | | |
| Fuelwood in HHs | 18,858 | 43,780 | 58,528 | 69,187,924 | 24.38% |
| Own charcoal use | | 6,468 | 1,039 | 4,142,400 | 1.46% |
| Cutting/charcoaling | 833 | 58,375 | 6,077 | 37,279,218 | 13.13% |
| Merchant income on top of the charcoal producers' income | | | | 2,730,000 | 0.96% |
| State tax revenue for charcoal sold outside area | | | | 5,460,000 | 1.92% |
| Trade & transport profit (estimate 40%) of charcoal sold outside area | | | | 5,460,000 | 1.92% |
| Other wood and NTFP utilization | | | | | |
| Own collected poles | 275 | 13,343 | 3,188 | 9,246,632 | 3.26% |
| Weeding income | | 27,367 | 4,033 | 17,401,218 | 6.13% |
| Fencing of fields | 1,311 | 0 | 0 | 1,626,134 | 0.57% |
| Fencing of hutyard | 0 | 2,327 | 2,118 | 2,092,048 | 0.74% |
| Annual honey production from framed area only | | | | 4,620,000 | 1.63% |
| **Total annual beneficial income** | | | | **283,830,429** | 100.00% |
| **COSTS** | | | | | |
| Prosopis cost to agriculture | | | | | |
| Tenant weeding fees (=16/30 tenants*14000 SD)*1240 tenant households | | | | 9,258,667 | 6.89% |
| Income loss from sharing (=5.33/30 ten.*70000SD+10.66/30 ten.*6000SD)*1240 | | | | 18,065,147 | 13.44% |
| Increased ploughing expenses (=90000 SD - 18000 SD)*16/30 tenants*1240 | | | | 47,616,000 | 35.43% |
| Irrigation water losses in feeder canals (=0.22*60000 SD)*16/30 tenants*1240 | | | | 8,729,600 | 6.50% |
| Tenant weeding labour cost (=average 10133 SD)*1240 tenat households | | | | 12,564,920 | 9.35% |
| Main canal annual cleaning & weeding maintenance in framed area | | | | 31,400,000 | 23.37% |
| Punctures of vehicle tyres | | | | 5,194,000 | 3.86% |
| Thorn injuries (medical treatment cost SD 20,000/patient) | 420,000 | 900,000 | 240,000 | 1,560,000 | 1.16% |
| **Total annual costs** | | | | **134,388,333** | 100.00% |
| **BENEFIT/COST RATIO[d]** | | | | **2.1** | |

Notes: **a)**: The real prosopis forage benefit provided by nature (economically non-internalized)
**b)**: Fodder efficiency is the annual livestock income (comprising sales of animals, and sales and subsistence use of meat and milk) divided by the total fodder value, that were all derived from household surveys.
**c)**: This value is the economically internalized prosopis forage value derived through multiplying the real prosopis forage value with the percentage derived from annual livestock income/ total fodder value.
**d)**: In case the non-internalized prosopis forage value is used the *Benefit/ Cost Ratio* would be: **4.1**

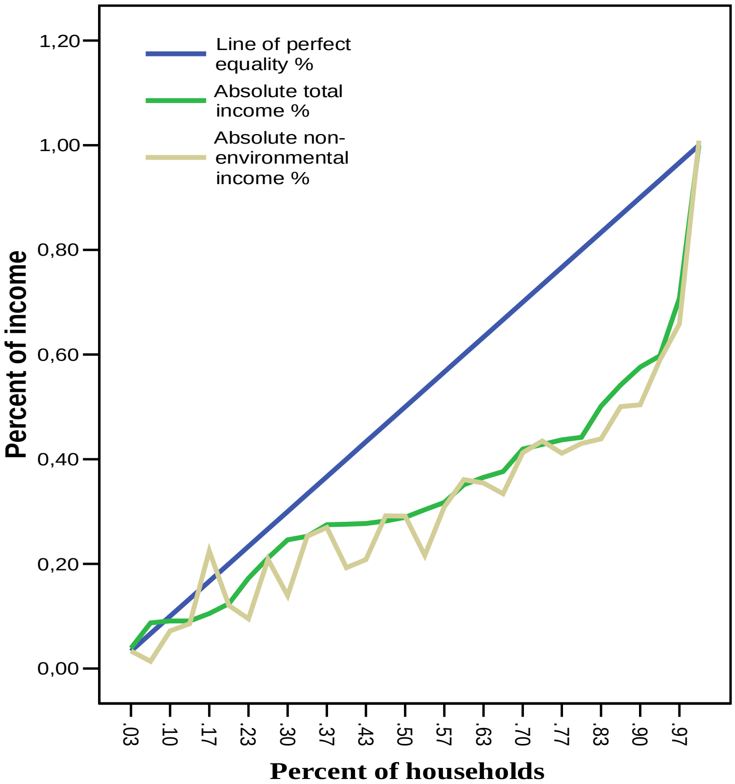



Figure 7. Lorenz curve for the tenant households in New Halfa Irrigation Scheme.

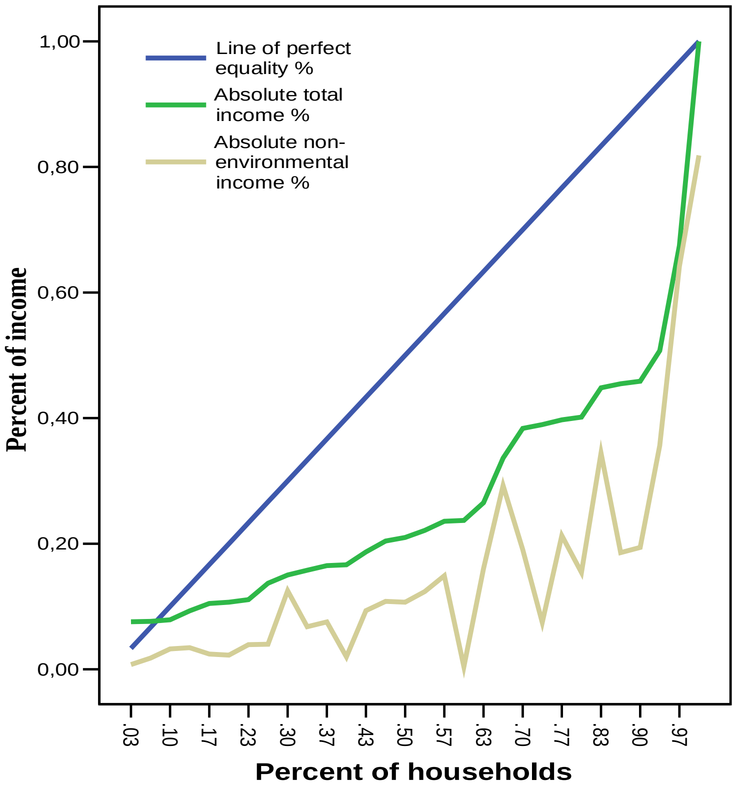



Figure 8. Lorenz curve for the western Sudanese landless households in New Halfa Irrigation Scheme.

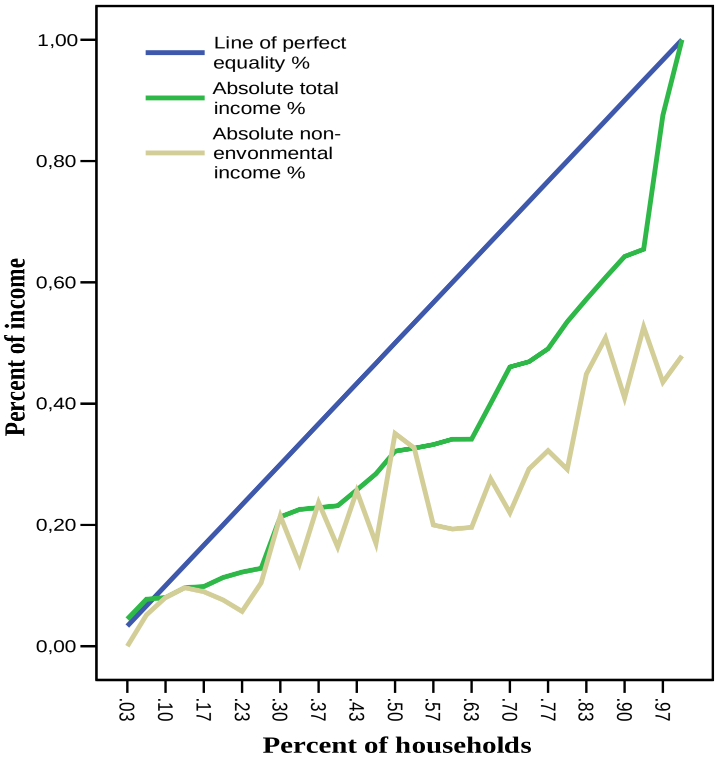



Figure 9. Lorenz curve for the eastern Sudanese landless households in New Halfa Irrigation Scheme

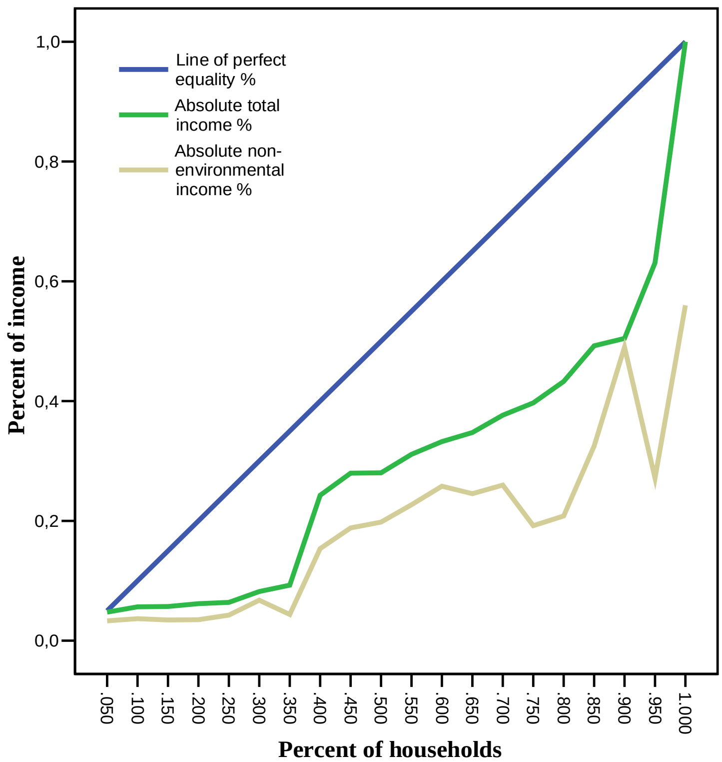



Figure 10. Lorenz curve for the nomad households in New Halfa Irrigation Scheme.

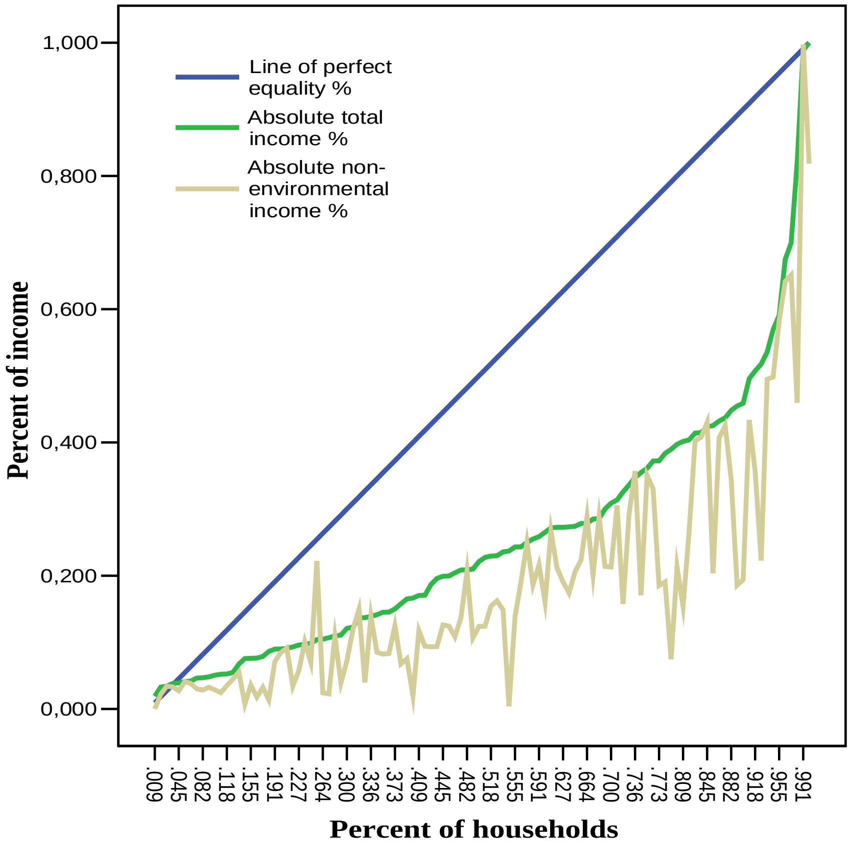



Figure 11. Lorenz curve for all population group households combined in New Halfa Irrigation Scheme.

Table 18. Structure of household economies in the framed research area of Gandato Scheme. (in Sudanese Dinars).

| **Household budget item** | **Income quintile** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | | **2** | | **3** | | **4** | | **5** | |
| N= 70 households | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. |
| Crop gross margin | | | | | | | | | | |
| Net cash income from crops | 29107 | 57965 | 3425 | 27768 | 56534 | 109275 | 114749 | 394617 | 679427 | 659995 |
| Net subsistence income from crops | 58754 | 81501 | 10607 | 20995 | 51043 | 83613 | 128280 | 236041 | 66518 | 71961 |
| Livestock net income/expenses | | | | | | | | | | |
| Net cash income from livestock | -47236 | 61684 | -35107 | 62211 | 5661 | 28626 | 49839 | 199013 | 39482 | 234890 |
| Net subsistence income | 36957 | 32592 | 27796 | 29035 | 20068 | 30088 | 59143 | 44048 | 59732 | 49262 |
| Net income of labour work | | | | | | | | | | |
| Net income of unskilled labour (excluding environ. labour) | 50571 | 63703 | 107786 | 112671 | 100257 | 126813 | 92857 | 146887 | 12857 | 48107 |
| Net Income from skilled labour work | 0 | 0 | 12857 | 48107 | 33143 | 68071 | 16071 | 48682 | 163929 | 371194 |
| Net income merchant/business | 16393 | 61337 | 42309 | 84085 | 50316 | 103748 | 189750 | 369352 | 458638 | 686072 |
| Net Remittances (private & pension) | 7286 | 27261 | 20571 | 76971 | 18857 | 51499 | 95143 | 116484 | 59143 | 86976 |
| **Absolute non-environmental cash income** | 56057 | 54042 | 151839 | 32749 | 264768 | 83327 | 558409 | 121416 | 1545707 | 726630 |
| **Absolute non-environmental subsistence income** | 94282 | 110466 | 43368 | 39639 | 71111 | 111798 | 187423 | 230749 | 126250 | 102064 |
| Environmental net income | | | | | | | | | | |
| Prosopis net cash income/expense | -14046 | 26035 | -18693 | 28061 | -19654 | 19072 | -24136 | 16967 | -42568 | 30203 |
| Environment. subsistence forage income | 268431 | 193859 | 204066 | 205674 | 208561 | 276301 | 701478 | 901868 | 705142 | 1455883 |
| **Absolute cash income** | 42011 | 37264 | 126148 | 27753 | 245114 | 74655 | 534274 | 116249 | 1503139 | 729362 |
| **Absolute subsistence income** | 328699 | 162886 | 268972 | 278625 | 279672 | 381541 | 869438 | 1119114 | 831392 | 1458038 |
| Annual sand invasion costs | -8986 | 14404 | -14752 | 26864 | -16338 | 28852 | -5657 | 10362 | -36829 | 55855 |
| Absolute cash income inclucive of sand invasion costs | 33025 | 29983 | 111396 | 34862 | 228776 | 57157 | 528616 | 108586 | 1357696 | 923927 |
| Total known household costs | -28871 | 32385 | -46629 | 23444 | -52571 | 20574 | -51671 | 21246 | -98557 | 116118 |
| **Absolute net cash income** | 4154 | 31088 | 64838 | 36393 | 176204 | 61220 | 477016 | 107681 | 1367753 | 672770 |

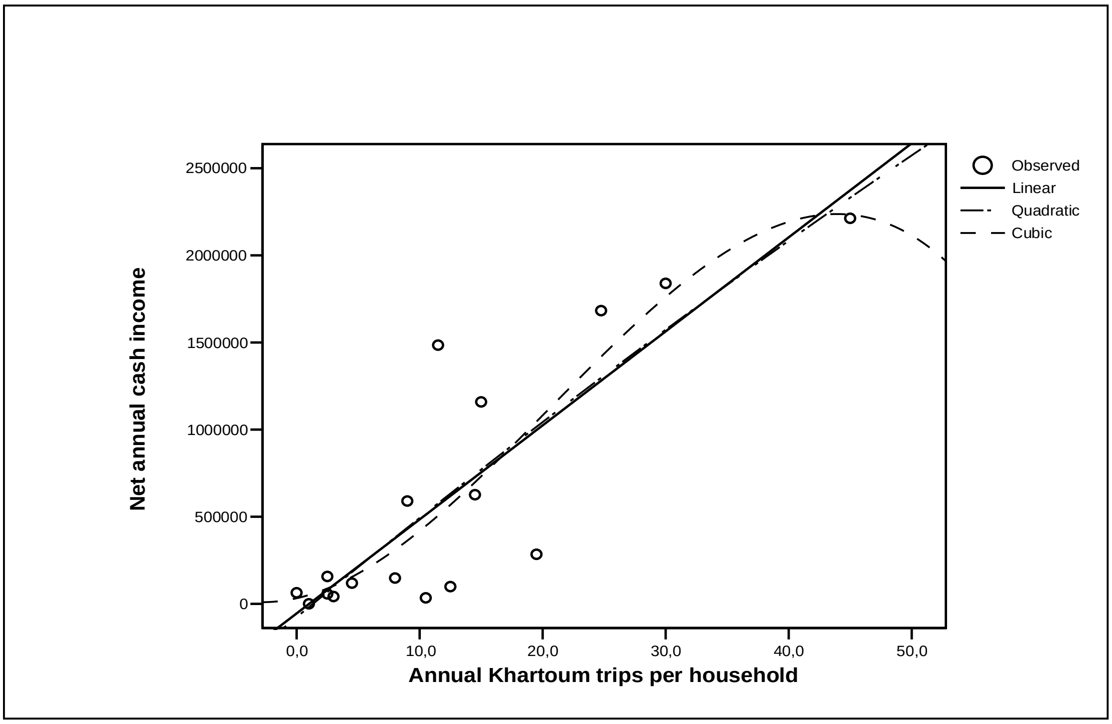



Figure 12. Correlation between net annual cash income and number of social visits per household in Al Hosh (Shendi visits estimated as ¼ of a Khartoum trip).

Table 20. Socio-economic background of Gandato Scheme framed research area households.

| **Household information** | **Income quintile** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | | **2** | | **3** | | **4** | | **5** | |
| N= 70 households | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. | Mean | s.d. |
| Age of household head/ respondent (years) | 46.7 | 17.7 | 39.5 | 13.8 | 38.6 | 14.9 | 45.9 | 21.3 | 43.9 | 17.1 |
| Education level (0,1,2) * of household head | 0.64 | 0.84 | 1.14 | 0.66 | 1.43 | 0.76 | 1.36 | 0.74 | 1.43 | 0.65 |
| Since when in this village/area | birth | | birth | | birth | | birth | | birth | |
| Ethnic background of households | Pastoral (Ababda mainly) 71.40 % | | Ababda/Gaali 50% both | | Gaali/Shaigya 71.40 % | | Gaali/Shaigya 64 % | | Shaigya/Gaali 57 % | |
| Amount of schemeland (feddans) | 1.50 | 2.50 | 0.57 | 1.50 | 0.96 | 1.71 | 3.82 | 5.50 | 6.43 | 4.03 |
| Amount of rainfed land (feddans) (mostly in remote valleys) | 2.93 | 3.67 | 0.43 | 1.16 | 0.07 | 0.27 | 0.14 | 0.36 | 0.00 | 0.00 |
| Household size (members) | 7.14 | 1.83 | 6.00 | 2.04 | 6.45 | 2.71 | 7.43 | 2.77 | 8.07 | 3.02 |
| Number of adults in household | 3.60 | 1.62 | 2.60 | 0.88 | 2.50 | 1.29 | 4.40 | 1.80 | 5.00 | 2.25 |

* Education level: 0 = no education, 1 = primary school, and 2 = secondary school or higher

Table 21. Utilization of prosopis and other environmental resources in Gandato Scheme households in 2002-03.

| N= 70 households | Income quintile | | | | | | | | | | Mean Abso-lute Total Income | Absolute Total Income (All 70 hh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Prosopis and other environmental income item** | **1** | | **2** | | **3** | | **4** | | **5** | | | |
| | mean | s.d. | mean | s.d. | mean | s.d. | mean | s.d. | mean | s.d. | | |
| * Other free-grazing forage (incl. remote valley forage) | 66,386 | *61,818* | 76,204 | *126,761* | 58,682 | *93,281* | 229,939 | *342,738* | 507,742 | 1,479,364 | 187,791 | 13,145,339 |
| * Prosopis free-grazing forage | 168,337 | *138,733* | 118,094 | *120,112* | 133,189 | *192,468* | 427,522 | *602,406* | 180,692 | *184,224* | 205,567 | 14,389,691 |
| * Fuelwood (collected) | 24,879 | *17,903* | 7,946 | *11,572* | 14,600 | *13,954* | 18,482 | *16,143* | 11,863 | *14,925* | 15,554 | 1,088,774 |
| * Fuelwood (selling) | 0 | *0* | 0 | *0* | 857 | *3,207* | 0 | *0* | 0 | *0* | 171 | 11,999 |
| * Prosopis poles (collected) | 907 | *1,276* | 1,068 | *2,646* | 250 | *643* | 946 | *827* | 1,075 | *1,180* | 849 | 59,450 |
| * Prosopis fence (installed) | 1,455 | *4,839* | 753 | *2,431* | 368 | *981* | 5,126 | *10,411* | 754 | *1,957* | 1,691 | 118,377 |
| * Fuelwood (purchased) | -7,161 | *13,476* | -16,300 | *17,985* | -6,518 | *11,558* | -2,607 | *9,755* | -7,300 | *13,506* | -7,977 | -558,400 |
| * Charcoal (purchased) | -600 | *1,681* | -7,714 | *10,894* | -9,171 | *11,095* | -8,743 | *10,045* | -11,161 | *13,704* | -7,478 | -523,450 |
| * Prosopis poles (purchased) | 0 | *0* | 0 | *0* | -321 | *1,203* | -2,071 | *5,413* | 0 | *0* | -479 | -33,499 |
| Weeding labour expenses | -6,286 | *12,840* | -1,607 | *6,013* | -4,500 | *10,494* | -10,714 | *13,157* | -24,107 | *25,932* | -9,443 | -660,999 |
| **TOTAL in Sudanese Dinars:** | | | | | | | | | | | | |
| Prosopis net cash income/outlay | -14,046 | *26,035* | -18,693 | *28,061* | -19,654 | *19,072* | -24,136 | *16,967* | -42,568 | *30,203* | -23,819 | -1,667,351 |
| Prosopis subsistence income | 176,355 | *92,038* | 146,611 | *168,862* | 148,407 | *193,787* | 452,077 | *598,782* | 194,384 | *185,881* | 223,567 | 15,649,675 |
| Total environmental subsistence income | 237,060 | *135,848* | 228,497 | *252,834* | 207,089 | *276,283* | 682,015 | *908,715* | 702,126 | 1,456,139 | 411,357 | 28,795,017 |

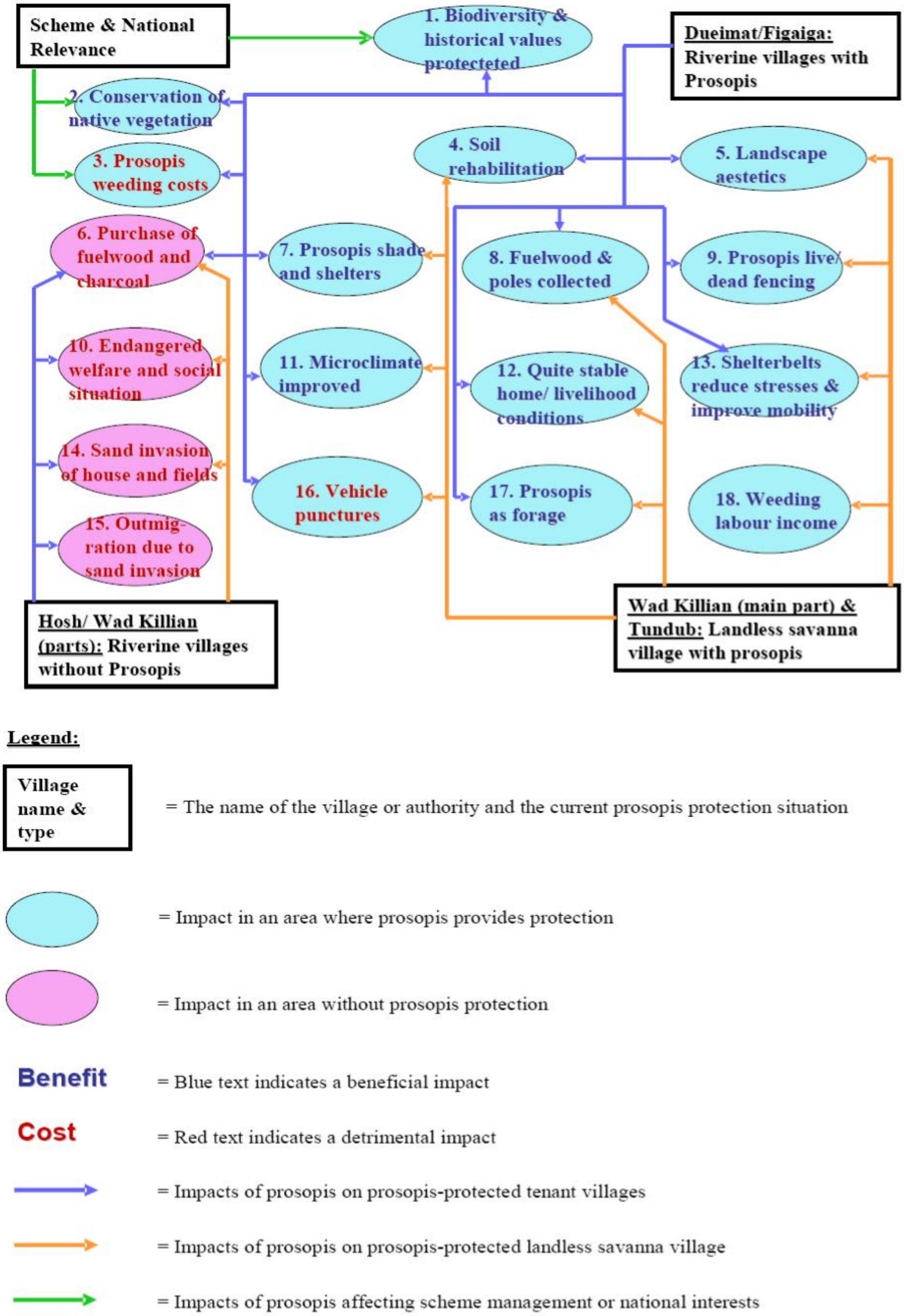



Figure 13. Impact of prosopis on households in the framed area of Gandato Irrigation Scheme.

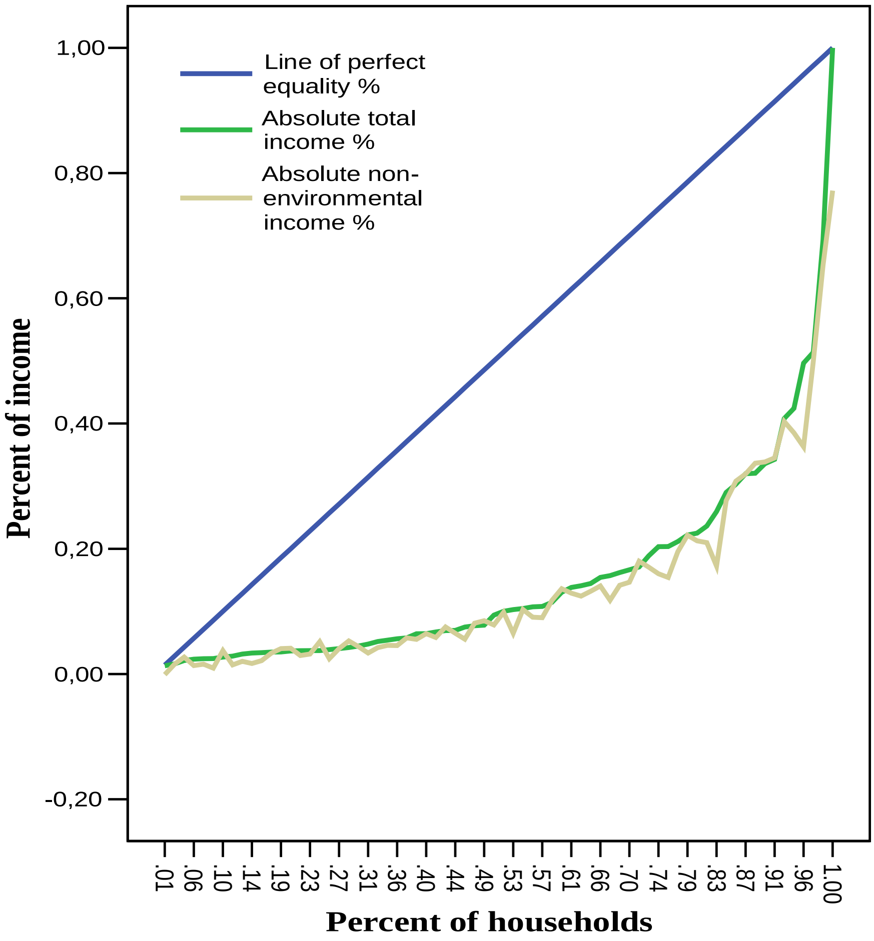



Figure 14. Lorenz curve for all households combined in Gandato Irrigation Scheme.

Table 22. Sand invasion in Al Hosh - situation assessment for 1992 to 2003.

| Village Assessment conducted in January 2004 | Banat al Hamda | Hosh al Hag | Hosh Wud Nura | Bagaria (Hassania) | Ed Dem | Hella Tuara | Helle Giddam | Total Al Hosh |
|---|---|---|---|---|---|---|---|---|
| Approx number of households | 250 | 150 | 80 | 70 | 100 | 150 | 50 | 850 |
| Year of first sandinvasion | 1989 | 1979 | 1990 | 1979 | 1989 | 1991 | not invaded | Since 1979 |
| Number of invaded houses | 65 | 60 | 55 | 70 | 30 | 45 | 0 | 325 |
| Number of HHs invaded last year | 17 | 12 | 10 | 70 | 11 | 15 | 0 | 135 |
| Number of houses destoyed | 50 | 50 | 40 | 70 | 20 | 30 | 0 | 260 |
| Total number of rebuilt houses | 30 | 25 | 10 | 70 | 15 | 25 | 0 | 175 |
| Number of houses rebuilt/ year: | 5 | 0 | 4 | 47 | 5 | 5 | 0 | 66 |
| Number of HHs excavating sand | 20 | 30, Some 50 hh too heavy to excavate | 40 | 70 hh have no yard thus no excavation | 10 | 20 | 0 | 190 |
| House/houseyard type | Normal house with yard | Normal house with yard | Normal house with yard | One room/no yard or 3 m high yard wall | Normal house with yard | Normal house with yard | Normal house with yard | Normal houses/ at sandedge primitive |
| Sand excavation hours | > 20 hh. excav. > 15 hours | > 20 hh. excav. > 15 hours | > 20 hh > 20 hours 14 hh < 5 hours | Too much to excavate | No sand dumping/ thus no excavation | No sand dumping/ thus no excavation | 0 | No sand dumping sites and thus only little sand excavation |
| Number of HHs moving house in yard | 5 | 20, movable wooden huts | 5 | 0 | 10, movable wooden huts | 25, move inside yard 8 - 10 m | 0 | 65 |
| Number of HHs move house within village | 10 | 10 | 2 | 10 | 5 | 5 | 0 | 42 |
| HH heads that commute to city | First step to move | Some considers | Met at least two HH | No one - pastoral background | Probably some | Probably some | Not due to sand | In all but one village parts several HHs |
| Type of persons who move to Khartoum | officemen, policemen, petty sellers, educated persons | officemen, policemen, petty sellers, educated persons | officemen, policemen, petty sellers, educated persons | 0 | policeman, merchants, educated men | officemen, policemen, petty sellers, educated persons | 0 | officemen, policemen, petty sellers, educated persons |
| Type of persons who move to Shendi | Donkey cart drivers, teachers, petty sellers, builders, & workers | Donkey cart drivers, teachers, petty sellers, builders, & workers | Donkey cart drivers, teachers, petty sellers, builders, & workers | No one so far | Teachers, two livestock merchants | Not known | 0 | Donkey cart drivers, teachers, petty sellers, builders, & workers |

Table 23. Sand invasion in Wad Killian - situation assessment for 1992 – 2003.

| **Village assessment conducted in January 2004** | **Wad Killian 1** | **Wad Killian 2 (unprotected)** | **Wad Killian 3 Shehab** | **Wad Killian 4** | **Wad Killian 5** | **Total Wad Killian** |
|---|---|---|---|---|---|---|
| Approx number of households | 200 | 30 | 30 | 15 | 6 | 281 |
| Year of first sand invasion | before 1991-92 | 17-18 years ago | before 1991-92 | Not known | Not known | Mid-1980s |
| Number of invaded houses/year | Before -91 ca. 50 hh after shelterbelt zero | 30 | No houses after 1991 - 1992 | No | No | Before 1991 almost all 170 hh/year invaded |
| Number of total rebuilt houses | Before 1991 > 50 hh | 30 | several before 1991 | No | No | Close to 100 |
| Number of houses rebuilt/year | Only new houses and expansion | All of them partly | No | No | No | Only the unprotected Wad Killian 2 |
| Number HHs excavating sand | About 30 do some sand excavation | No one as no yard | About 10 | No | No | About 40 |
| House/houseyard type | Standard with yards expanding when cash | Single room houses < 20000 SD value | Standard with yard expanding houses | Standard with yards expanding houses | Standard with yards expanding houses | Standard except WK2 expanding houses |
| Sand excavation hours | 22 hh > 6 h and some excavate 3 hours | Just rebuild or let sand pass by | < 6 h/year | Very little as within prosopis shelterbelt | Very little as within prosopis shelterbelt | Varies from 0 to 10 h |
| Number of HHs that move house in yard | No one | No yard, houses far apart instead | No | No | No | No |
| Number of HHs that move house in village | No one | No, poor people & low social status | No | No | No | No one since 1992 |
| Number of HHs resettling in Shendi | No one, but men commuting there | No money | No | No | No | No one, but men commuting |
| Type of professions of household head | Workers of all kind work outside village | Unemployed or petty workers | Business and labourer house-holds | Not known | Not known | Range from extreme poor to wealthiest hh interviewed |

Table 24. Impact of shelterbelts on total crop yield in Gandato framed research area.

| Village | Garden | Alfa-alfa | Sudanese Bean | Onion | Vege-tables | Average Total Feddans in use | Total Unit Income SD |
|---|---|---|---|---|---|---|---|
| **No Shelterbelt (Al Hosh)** | | | | | | (1999-2002) | |
| Average annual feddans in use | 7.71 | 35.42 | 89.70 | 59.04 | 11.32 | **203.19** | |
| Rescaled percentual share ( 100%) of total | | 17.4 | 44.1 | 29.1 | | | |
| Amount (fodder unit or sacks)/feddan | | 1 | 3.6 | 54.4 | | | |
| 2003 price (fodder field or sack)/feddan | | 170,000 | 23,200 | 5,980 | | | |
| Gross Income/feddan in SD (in 2003) | | 170,000 | 83,520 | 325,312 | | | |
| Share of unit income in SD (in 2003) | | 29,633 | 36,869 | 94,520 | | | 161,021 |
| Total unit income SD x total feddans | | | | | | | 32,717,954 |
| **Shelterbelt (Al Figaiga&Dueimat)** | | | | | | | |
| Average annual feddans calculated and scaled to Al Hosh size | 30.41 | 67.82 | 175.63 | 45.15 | 3.99 | **323.00** | |
| Rescaled percentual share ( 100%) of total | | 21.0 | 54.4 | 14.0 | | | |
| Amount (fodder unit or sacks)/feddan | | 1 | 5.4 | 78.3 | | | |
| 2003 price (fodder field or sack)/feddan | | 192,056 | 23,200 | 5,980 | | | |
| Gross Income/feddan in SD (in 2003) | | 192,056 | 125,280 | 468,234 | | | |
| Share of unit income in SD (in 2003) | | 40,326 | 68,121 | 65,451 | | | 173,898 |
| Total unit income SD x total feddans | | | | | | | 56,168,929 |
| Unit difference between no shelterbelt and shelterbelt in Sudanese dinars | | | | | | | -12,876 |

**Scenario A.**

Total gross income difference in SD between unprotected Al Hosh fields and protected ones (calculations as follows: ((323.0 – 203.19) * - 173,898) – (203.19*- 12,876) = - 23,450,975) **-23,450,975**

**Scenario B.**

Gross income reduction in Al Figaiga/Dueimat in case of no shelterbelts (80% of Scenario A) **-18,760,780**

Total gross income difference in SD for the non-prosopis situation (no shelterbelts) (calculated as follows: Scenario A + Scenario B) **-42,212,077**

Table 25. Nursery, planting, irrigation and tending expenses for shelterbelt for Gandato in 2004.

| **Item** | **Amount** | **Price/ Unit SD** | **Total SD** | **Total € 2004** |
|---|---|---|---|---|
| *Nursery* | | | | |
| Polythene bags | 5,400 | -2 | -10,800 | |
| Clay soil | 4 | -1,250 | -4,500 | |
| Water | 600 | -6 | -3,600 | |
| Seeds | 7 | -1,000 | -6,800 | |
| Filling polythene bags | 5,400 | -1 | -5,400 | |
| Sowing | 5,400 | -1 | -5,400 | |
| Preparation of seedl beds | 0 | 0 | 0 | |
| *Subtotal* | | | -36,500 | |
| *Planting out* | | | | |
| Land preparation | 1 | -10,000 | -14,181 | |
| Transportation of seedl | 1 | -10,000 | -10,000 | |
| Planting | 1 | 2,000 | 2,836 | |
| Irrigation | | | 0 | |
| Guarding | 54 | -12,000 | -648,000 | |
| Technical supervision | 8 | -35,000 | -280,000 | |
| *Subtotal* | | | -949,345 | |
| **Total nursery and planting** | | | **-985,845** | **-3,130** |

*Seedlings needed in the shelterbelts:* 2.25 km x 400 = 900 seedlings/ row x 3 rows = totally 2700 seedlings to be planted

*Times of irrigation/period:*

| Months after planting | **1+2** | **3+..5** | **6+...10** | **11+...15** | **16+...24** |
|---|---|---|---|---|---|
| * Alternative **1**: | 9 | 13 | 22 | 23 | 38 |
| * Alternative **2**: | 6 | 8 | 11 | 12 | 19 |
| * Alternative **3**: | 3 | 5 | 5 | 5 | 9 |
| | | | | | |
| *Water(litre)/irrigated tree* | 10 | 30 | 75 | 120 | 175 |
| *Needed water in litre/ irr.time:* | 27,000 | 81,000 | 202,500 | 324,000 | 472,500 |

One tanker contains 4,000 litres and cost 10,000 Sudanese dinars

| *Tankers needed/irrigation:* | **1+2** | **3+..5** | **6+..10** | **11+..15** | **16+..24** | **Total** | **Tanker irrigation: Total cost SD for activity** | **Total cost in Euros** |
|---|---|---|---|---|---|---|---|---|
| * Alternative **1**: | 61 | 263 | 1,114 | 1,863 | 4,442 | 7,742 | -77,422,500 | -245,786 |
| * Alternative **2**: | 41 | 162 | 557 | 972 | 2,244 | 3,976 | -39,757,500 | -126,214 |
| * Alternative **3**: | 20 | 101 | 253 | 405 | 1,063 | 1,843 | -18,427,500 | -58,500 |

| *Irrigation with three wells* | |
|---|---|
| Building three new wells | -1,200,000 |
| Pumphouses | -300,000 |
| Spare parts 2 years | -150,000 |
| Kerosene 2 years | -4,368,000 |
| Sand catchment | -300,000 |
| 3x500 m long hoses | -150,000 |
| Pump operators | -1,080,000 |
| **Total for well irrigation (SD)** | **-7,548,000** |

| **Realizable alternatives:** | **Total cost SD for activity** | **Total cost in Euros** |
|---|---|---|
| Alternative **A**: Irrigation alternative no. **3** & three bore wells, labour and mgt. | -26,961,345 | -85,592 |
| Alternative **B**: Only three bore wells, labour and management | -8,533,845 | -27,092 |
| **Selected Alternative A., which was then divided by 25 years** | **-1,078,454** | -3,424 |

Table 26. Assessment of livestock/donkey populations in Scenario A and B situations in the surveyed households in Gandato framed area for 2003.

| **Type of Animal & Case situation** | **Livestock reared around the villages:** | | | | **Total amount of livestock reared in villages** | **Livestock/ household in villages** | **Livestock reared as business & in remote villages** |
|---|---|---|---|---|---|---|---|
| | **Al Hosh** | **Dueimat & Al Figaiga** | **Wad Killian** | **Tundub **** | | | |
| A. Absolute livestock populations in 2003 | | | | | | | |
| * goats | 107 | 135 | 54 | 88 | 384 | 5.5 | 10 |
| * sheep | 18 | 59 | 32 | 17 | 126 | 1.8 | 320 |
| * cows | 12 | 22 | 5 | 3 | 42 | 0.6 | 8 |
| * donkeys | 14 | 21 | 18 | 10 | 63 | 0.9 | 6 |
| B. Animal feeding units in 2003 | | | | | | | |
| * goats | 83.67 | 98.3 | 45.45 | 67 | 294.4 | 4.2 | 8.3 |
| * sheep | 14 | 47.5 | 23.85 | 13 | 98.35 | 1.4 | 117.5 |
| * cows | 12 | 21.5 | 4.5 | 1 | 39 | 0.6 | 7 |
| * donkeys | 13.5 | 19.5 | 18 | 10 | 61 | 0.9 | 5.5 |
| C. Hypothetical animal feeding units without prosopis in 2003 | | | | | | | |
| * goats | 36.17 | 61.5 | 23.9 | 39.33 | 160.9 | 2.3 | 8.3 |
| * sheep | 9 | 14 | 4 | 5 | 67 | 1.0 | 95 |
| * cows | 5 | 13 | 0 | 0 | 18 | 0.3 | 7 |
| * donkeys | 9.5 | 14 | 12 | 5 | 40.5 | 0.6 | 5.5 |
| D. Hypothetical percentage livestock kept when prosopis is absent (alt. C/alt. B) in 2003 (%) | | | | | | | |
| * goats | 43.2 | 62.6 | 52.6 | 58.7 | 54.7 | 54.7 | 100.0 |
| * sheep | 64.3 | 29.5 | 16.8 | 38.5 | 68.1 | 68.1 | 80.9 |
| * cows | 41.7 | 60.5 | 0.0 | 0.0 | 46.2 | 46.2 | 100.0 |
| * donkeys | 70.4 | 71.8 | 66.7 | 50.0 | 66.4 | 66.4 | 100.0 |

** Tundub figures are hypothetical estimates based on 26 profiled households from the other villages. In reality one household was observed to have 15 heads of cattle.

Table 27. Percentual shares of various types of fodder in Scenarios A and B for the framed area of Gandato in 2003.

| **Fodder type & Scenario** Extrapolated for the whole villages | **Al Hosh** Sudanese Dinars | % | **Figaiga & Dueimat** Sudanese Dinars | % | **Wad Killian** Sudanese Dinars | % | **Total all households** Sudanese Dinars | % |
|---|---|---|---|---|---|---|---|---|
| **A. With prosopis** | | | | | | | | |
| Own cultivated fodder | 598,500 | 8.7 | 1,796,325 | 15.0 | 190,400 | 3.6 | 2,585,225 | 10.7 |
| Grazing in field or valley | 1,305,107 | 19.1 | 1,504,437 | 12.5 | 209,700 | 4.0 | 3,019,244 | 12.5 |
| Other free-grazing forage | 617,785 | 9.0 | 1,575,413 | 13.1 | 1,000,344 | 19.1 | 3,193,542 | 13.3 |
| Prosopis free-grazing forage | 3,161,676 | 46.2 | 5,821,976 | 48.5 | 3,210,731 | 61.4 | 12,194,383 | 50.6 |
| Buying of fodder | 1,165,750 | 17.0 | 1,303,900 | 10.9 | 613,800 | 11.7 | 3,083,450 | 12.8 |
| **Total** | **6,848,818** | 100.0 | **12,002,051** | 100.0 | **5,224,975** | 100.0 | **24,075,844** | 100.0 |
| Number of households included in estimate | 24 | | 27 | | 17 | | 68 | |
| **B. Without prosopis** | | | | | | | | |
| Own cultivated fodder | 598,500 | 17.6 | 1,796,325 | 28.9 | 190,400 | 9.5 | 2,585,225 | 22.2 |
| Grazing in field or valley | 1,265,294 | 37.2 | 1,521,687 | 24.5 | 209,700 | 10.5 | 2,996,681 | 25.8 |
| Other free-grazing forage | 142,368 | 4.2 | 332,510 | 5.3 | 244,136 | 12.2 | 719,014 | 6.2 |
| Prosopis free-grazing forage | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Buying of fodder | 1,393,588 | 41.0 | 2,572,728 | 41.3 | 1,359,614 | 67.9 | 5,325,930 | 45.8 |
| **Total** | **3,399,750** | 100.0 | **6,223,250** | 100.0 | **2,003,850** | 100.0 | **11,626,850** | 100.0 |
| Number of households included in estimate | 24 | | 27 | | 17 | | 68 | |
| **Share of B from A (%)** | **49.6** | | **51.9** | | **38.4** | | **48.3** | |

Table 28. Normative statistics on interviewed households' perception of scenic attributes of prosopis in Gandato Scheme.

| **Villagers' opinion on prosopis:** | **Al Hosh** | **Figaiga & Dueimat** | **Wad Killian** | **Average opinion weighed per:** All 62 respon-dents | Accumul. village results / 3 | All village HHs incl. | **Neutral result** to compare with |
|---|---|---|---|---|---|---|---|
| * Prosopis good or bad (1 - 5) | 2.96 | 4.14 | 1.50 | 2.94 | 2.87 | 2.81 | 3.00 |
| * Prosopis beautiful or ugly (1 or 2) | 1.44 | 1.71 | 1.06 | 1.42 | 1.40 | 1.39 | 1.50 |
| Number of households analyzed | 23 | 21 | 18 | 62 respon-dents | 3 villages | 1315 HHs weighed | |

Table 29. Group names of birds observed by the researcher in Shendi area in January 2004.

| Group Name (Scientific) | Group Name (English) | Group Name (Swedish) |
|---|---|---|
| Pelecanidae | Pelicans | Pelikaner |
| Phalacrocoracidae | Cormorants | Skarvar |
| Ardeidae | Herons, Egrets | Hägrar |
| Ardeidae | Bitterns | Rördrommar |
| Threskiornithidae | Ibis storks | Ibisar |
| Ciconniidae | Storks | Storkar |
| Anatinae | Ducks | Änder |
| Milvus | Kites | Glador |
| Buteo, Accipiter | Buzzards | Vråkar |
| Aquila | Steppe eagles/ eagles | Stäppörnar, Örnar |
| Pandion halietus | Osprey | Fiskgjuse |
| Circus | Harriers | Kärrhökar |
| Falconidae | Falcons | Falkar |
| Phasanidae | Pearlhens | Pärlhöns |
| Pteroclidae | Sandgrouse | Flyghöns |
| Rallidae | Rails | Rallar |
| Vanellus | Plovers | Vadare: Vipor |
| Scolopacidae | Plovers | Vadare: Småvadare |
| Tringa | Sandpipers, Redshank | Vadare: Storsnäppor |
| Numenius, Recurvirostridae | Curlew, Godwits, Avocet | Vadare: Spovar |
| Limosa | Woodcocks | Vadare: Morkullor |
| Columbidae | Pigeons | Duvor |
| Streptopelia | Doves | Turturduvor |
| Cuculidae | Cuckoos | Gökar |
| Stringidae | Owls | Ugglor |
| Caprimulgidae | Nightjars | Nattskärror |
| Apodidae | Swifts | Seglare |
| Meropidae | Bee-eaters | Biätare |
| Coraciidae | Rollers | Blåkråkor |
| Alcedidae | Kingfishers | Kungsfiskare |
| Upupidae | Hoopoes | Härfåglar |
| Alaudidae | Larks | Lärkor |
| Hirundinidae | Swallows | Svalor |
| Motacillidae | Pipits | Piplärkor |
| Motacilla | Wagtails | Ärlor |
| Pycnonotidae | Bulbuls | Bulbyler |
| Laniidae | Shrikes | Törnskator |
| Prunellidae | Dunnoks/ Accentor | Järnsparvar |
| Sylviidae | Warblers | Sångare |
| Acrocephalus | Warblers | Rörsångare |
| Hippolais | Warblers | Gulsångare |
| Sylvia | Warblers | Sylvior |
| Phylloscopus | Warblers | Lövsångare |
| Muscicapidae | Flycatchers | Flugsnappare |

| | | |
|---|---|---|
| Saxicola | Whinchat | Buskskvättor |
| Monticola | Rock trush | Stentrast |
| Oenanthe | Stonechat | Stenskvättor |
| Phoenicurnus | Redstarts | Rödstjärtar |
| Luscinia | Nightingales | Näktergalar |
| Turdus | Trushes | Trastar |
| Nectariniidae | Sunbirds | Solfåglar |
| Emberizidae | Buntings | Fältsparvar |
| Emberizidae | Yellowhammer | Gulsparvar |
| Fringillidae | Finches | Finkar |
| Phodopechys sp. | Finches | Ökenfinkar |
| Acanthis | Siskins, Finches | Siskor |
| Ploceidae | Sparrows | Sparvfinkar |
| Sturnidae | Starlings | Starar |
| Corvidae | Crow birds | Kråkfåglar |
| Corvus | Ravens | Korpar |
| Pica | Magpie | Skata |

Table 30. List of native and introduced tree species in the Al Glea riverine area identified in July 2003.

Identified by Negwa ElSharif (Head of FNC in Shendi) and Jörn Laxén

| | |
|---|---|
| *Abutilon figarianum* Webb | |
| *Acacia ehrenbergiana* Hayne | |
| *Acacia nilotica* (L.) Willd. ex Delile | |
| *Acacia seyal* Delile | |
| *Acacia tortilis* (Forssk.) Hayne | |
| *Azadirachta indica* A. Juss. | (neem) |
| *Calotropis procera* (Aiton) W.T. Aiton | |
| *Capparis decidua* (Forssk.) Edgew. | |
| *Citrus* spp. L. | (orange, lemon, lime, and grapefruit) |
| *Eucalyptus microtheca* F. Muell. | |
| *Hyphaene thebaica* Mart. | (doum palm) |
| *Khaya senegalensis* (Desr.) A. Juss. | (African mahogany) |
| *Mangifera indica* L. | (mango) |
| *Milicia excelsa* (Welw.) C.C. Berg | (iroko) |
| *Pithecellobium dulce* (Roxb.) Benth. | |
| *Parkinsonia aculeata* L. | |
| *Phoenix dactylifera* L. | (date palm) |
| *Prosopis juliflora* (Sw.) DC. | |
| *Psidium guajava* L. | (guava tree) |
| *Salvadora persica* L. | |
| *Tamarindus indica* L. | (tamarind) |
| *Tectona grandis* L.f. | (teak) |
| *Ziziphus spina-christi* (L.) Desf. | |

**Table 31. Propsopis TEV study for scenarios A and B** (figures given in Sudanese Dinars, SD).
Community viewpoint on benefits and social costs.

**A. Current Scenario with prosopis in the villages**

| **Name of village** | **Al Hosh** | | **Figaiga/ Dueimat** | | **Wad Killian** | | **Tundub** | | **Total all villages** |
|---|---|---|---|---|---|---|---|---|---|
| **Total number of households/village** | **850** | | **185** | | **280** | | **75** | | **1,390** |
| **Impact Item** | **Unit cost/ Total impact** | **HHs/units affected** | **Unit cost/ Total impact** | **HHS/ units affected** | **Unit cost/ Total impact** | **HHs/ units affected** | **Unit cost/ Total impact** | **HHs/ units affected** | **Total Impact** |
| Sand invasion of houses and yards: | | | | | | | | | |
| **1. Annual loss in housing quality due to sand invasion:** | **-30,594,480** | | **0** | | **-8,020,000** | | **-2,740,350** | | **-41,354,830** |
| * Heavily affected households | -103,333 | 194 | 0 | 0 | -230,000 | 30 | 0 | 0 | |
| * Other households affected by sand | -50,938 | 131 | 0 | 0 | -28,000 | 40 | -36,538 | 75 | |
| * No direct sand impact | 0 | 525 | 0 | 185 | 0 | 210 | 0 | 0 | |
| * House value loss for resettlers | -250,000 | 15.5 | 0 | 0 | 0 | 0 | 0 | 0 | |
| **2. Annual sand excavation needs:** | **-1,920,000** | | **0** | | **-456,000** | | **-456,000** | | **-2,832,000** |
| * Heavily affected households | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| * Other households affected by sand | -48,000 | 40 | 0 | 0 | -11400 | 40 | -11400 | 40 | |
| **3. Annual rebuilding of house costs:** | **-6,877,000** | | **0** | | **-300,000** | | **-682,725** | | **-7,859,725** |
| * Heavily affected households | -84,500 | 66 | 0 | 0 | -10,000 | 30 | 0 | | |
| * Other households affected by sand | -26,000 | 50 | 0 | 0 | 0 | 0 | -9,103 | 75 | |
| * Slight or no house building | 0 | 734 | 0 | 185 | 0 | 250 | 0 | | |
| **4. Moving house site in village:** | **-1,013,000** | | **0** | | **0** | | **0** | | **-1,013,000** |
| * Moving and rebuilding | -202,600 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | |
| **5. Microclimate for crops improved:** | Impact of shelterbelt on crop profitability in Al Hosh | | | | | | | | **-23,450,975** |
| * Increased crop yield/feddan | * Combines all these impacts | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| * Potential to grow more demanding crop | * combined with the above impact | | | | | | | | |
| * Protection against land property loss | * combined with the above impact | | | | | | | | |
| **6. Livestock fodder costs:** | **-41,287,050** | | **-8,934,205** | | **-12,195,680** | | **-2,926,125** | | **-65,343,060** |
| * Fodder costs with prosopis to keep current milk and meat production | -48,573 | 850 | -48,293 | 185 | -43,556 | 280 | -39,015 | 75 | |
| **7. Milk & meat prices lower/stable:** | positive | | positive | | positive | | positive | | **Positive** |
| **8. Conservation of local acacia forests:** | **135,780,000** | | **19,340,615** | | **46,886,840** | | **14,457,225** | | **216,464,680** |
| * Prosopis fuelwood bakeries (times 5) | 5,730,000 | 1 | 900,000 | 1 | 0 | 0 | 3,300,000 | 1 | |
| * Prosopis fuelwood (times 5) | 140,130 | 850 | 81,110 | 185 | 158,115 | 280 | 129,840 | 75 | |
| * Prosopis poles (times 5) | 9,020 | 850 | 5,360 | 185 | 5,205 | 280 | 15,500 | 75 | |
| * Prosopis charcoal | 3,850 | 850 | 13,209 | 185 | 4,133 | 280 | 3,423 | 75 | |
| **9. Use of fencing and animal sheds:** | **-162,714** | | **341,288** | | **180,348** | | **37,788** | | **396,710** |
| * Prosopis fencing along the agri fields | -93,182 | 1 | 125,455 | 1 | 5,348 | 1 | 0 | 0 | |
| * Prosopis trees/built goat/sheep sheds | -25,563 | 1+849 | 722 | 185 | 559 | 250 | 442 | 75 | |
| * Prosopis trees or built cow sheds | -267 | 850 | 444 | 185 | 141 | 250 | 62 | 75 | |
| **10. Impact of prosopis on livelihoods at unprotected sand edge:** | positive | | positive | | positive | | positive | | **Positive** |
| * Net income reduction for merchants, labour; | | | | | | | | | |
| * Education in sand invasion households reduced; | | | | | | | | | |
| **11. Loss of income due to social visiting:** | **-2,052,036** | | **0** | | **0** | | **0** | | **-2,052,036** |
| * Household heads' worktime lost due to social visits | -2,414 | 850 | 0 | | 0 | | 0 | | |
| **12. Sand-induced visiting costs:** | **-16,456,036** | | **0** | | **0** | | **-733,275** | | **-17,189,513** |
| * Travel to Khartoum | -19,928 | 850 | 0 | 185 | 0 | 280 | -6,985 | 75 | |
| * Travel to Shendi | -18,504 | 850 | 0 | 185 | 0 | 280 | -2,792 | 75 | |

| Name of village | Al Hosh | | Figaiga/ Dueimat | | Wad Killian | | Tundub | | Total all villages |
|---|---|---|---|---|---|---|---|---|---|
| **Total number of households/village** | **850** | | **185** | | **280** | | **75** | | **1,390** |
| **Impact Item** | **Unit cost/ Total impact** | **HHs/units affected** | **Unit cost/ Total impact** | **HHS/ units affected** | **Unit cost/ Total impact** | **HHs/ units affected** | **Unit cost/ Total impact** | **HHs/ units affected** | **Total Impact** |
| **13. Landscape aesthetics:** | | | | | | | | | **0** |
| * Prosopis good or bad (1 - 5) | almost neutral | 850 | negative | 185 | positive | 280 | Na | Na | Almost neutral |
| * Prosopis beautiful or ugly (1 or 2) | almost neutral | 850 | negative | 185 | positive | 280 | Na | Na | Almost neutral |
| **14. Health and mobility issues:** | -1,078,454 | | | | | | | | **-1,078,454** |
| * Reduced insomnia problems at sand edge | Calculated as shadow project for nursery, planting and shelterbelt establishment from Wad Killian to Al Hosh northern parts | | | | | | | | |
| * Reduced health vulnerability | Same | | | | | | | | |
| * Reduced allergy/respiratory diseases | Same | | | | | | | | |
| * Stabilized soil for mobility | Description in text separately, although also part of the above | | | | | | | | |
| **15. Rehabilitation of soil and land:** | Combined with 14. Health issues as otherwise overlapping | | | | | | | | **0** |
| * Reduced sandstorm intensity/frequency | Calculated as shadow project for nursery, planting and shelterbelt establishment from Wad Killian to Al Hosh northern parts | | | | | | | | |
| * Stablized soil and vegetation | Same | | | | | | | | |
| * Reduced runoff/improved soil porosity | Same | | | | | | | | |
| **16. Biodiversity of riverine area:** | positive | | positive | | positive | | positiive | | **Positive** |
| **17. Protection of historical/ archaeological sites:** | positive | | positive | | positive | | positiive | | **Positive** |
| **18. Prosopis related direct expenses:** | **-12,660,900** | | **-4,177,020** | | **-960,000** | | **-10,400** | | **-17,808,320** |
| * Prosopis main canal weeding expenses | -1,200,000 | 1 | -420,000 | 1 | 0 | 0 | 0 | 0 | |
| * Weeding costs in agricultural field | -13,458 | 850 | -13,352 | 185 | 0 | 0 | 0 | 0 | |
| * Car and carriot punctures | -21,600 | 1 | -347,900 | 1 | -720,000 | 1 | -10,400 | 1 | |
| * Truck and tractor punctures | 0 | 0 | -939,000 | 1 | -240,000 | 1 | 0 | 0 | |

**B. Scenario without prosopis in the area** (figures are given in Sudanese Dinars, SD)

| **Name of village** | **Al Hosh** | | **Figaiga/ Dueimat** | | **Wad Killian** | | **Tundub** | | **Total all villages** |
|---|---|---|---|---|---|---|---|---|---|
| **Total number of households/village** | **850** | | **185** | | **280** | | **75** | | **1,390** |
| | **Unit cost/** | **HHs/units** | **Unit cost/** | **HHS/ units** | **Unit cost/** | **HHs/ units** | **Unit cost/** | **HHs/ units** | **Total** |
| **Impact Item** | **Total impact** | **affected** | **Total impact** | **affected** | **Total impact** | **affected** | **Total impact** | **affected** | **Impact** |
| <u>Sand invasion of houses and yards:</u> | | | | | | | | | |
| **1. Annual loss in housing quality due to** | | | | 185 | | | | | |
| **sand invasion:** | **-30,594,480** | | **-11,983,292** | | **-46,340,000** | | **-4,576,114** | | **-93,493,886** |
| * Heavily affected households | -103,333 | 194 | -108,333 | 60 | -230,000 | 135 | 0 | 0 | |
| * Other households affected by sand | -50,938 | 131 | -58,333 | 64 | -101,000 | 140 | -58,461 | 74 | |
| * No direct sand impact | 0 | 525 | 0 | 54 | 0 | 0 | 0 | 0 | |
| * House value loss for resettlers | -250,000 | 16 | -250,000 | 7 | -230,000 | 5 | -250,000 | 1 | |
| | | | | | | | | | |
| **2. Annual sand excavation needs:** | **-1,920,000** | | **-3,120,000** | | **-3,360,000** | | **-1,440,000** | | **-9,840,000** |
| * Heavily affected households | 0 | 0 | -48,000 | 30 | 0 | | -48,000 | 20 | |
| * Other households affected by sand | -48,000 | 40 | -24,000 | 70 | -24,000 | 140 | -24,000 | 20 | |
| | | | | | | | | | |
| **3. Annual rebuilding of house costs:** | **-6,877,000** | | **-3,950,000** | | **-9,231,440** | | **-2,932,725** | | **-22,991,165** |
| * Heavily affected households | -84,500 | 66 | -132,500 | 20 | -10,000 | 135 | 0 | 0 | |
| * Other households affected by sand | -26,000 | 50 | -26,000 | 50 | -84,444 | 93 | -39,103 | 75 | |
| | | | | | | | | | |
| **4. Moving house site in village:** | **-5,065,000** | | **-202,600** | | **0** | | **-405,200** | | **-5,672,800** |
| * Moving and rebuilding | -1,013,000 | 5 | -202,600 | 1 | 0 | 0 | -202,600 | 2 | |
| | | | | | | | | | |
| **5. Microclimate for crops improved:** | <u>Impact of unprotected fields on cropping profitability in A Figaiga, Dueimat and Al Hosh</u> | | | | | | | | **-42,211,755** |
| * Increased crop yield/feddan | Combines all these impacts | | | | | | | | |
| * Potential to grow more demanding crop | combined with the above impact | | | | | | | | |
| * Protection against land property loss | combined with the above impact | | | | | | | | |
| | | | | | | | | | |
| **6. Livestock fodder externalities:** | **-404,729,200** | | **-59,012,780** | | **-76,280,120** | | **-11,163,450** | | **-551,185,550** |
| * Fodder costs in non-prosopis case | -476,152 | 850 | -318,988 | 185 | -272,429 | 280 | -148,846 | 75 | |

to keep current milk and meat production

| Name of village | Al Hosh | | Figaiga/ Dueimat | | Wad Killian | | Tundub | | Total all villages |
|---|---|---|---|---|---|---|---|---|---|
| **Total number of households/village** | **850** | | **185** | | **280** | | **75** | | **1,390** |
| **Impact Item** | **Unit cost/ Total impact** | **HHs/units affected** | **Unit cost/ Total impact** | **HHS/ units affected** | **Unit cost/ Total impact** | **HHs/ units affected** | **Unit cost/ Total impact** | **HHs/ units affected** | **Total Impact** |
| **7. Milk & meat prices raise/fluctuate** | negative | | negative | | negative | | negative | | **Negative** |
| **8. Conservation of local acacia forests:** | **-23,229,000** | | **-935,725** | | **-7,988,680** | | **-2,562,375** | | **-34,715,780** |
| * Local acacia fuelwood for bakeries | -1,146,000 | 1 | -180,000 | 1 | 0 | 0 | -660,000 | 1 | |
| * Local acacia fuelwood | -28,026 | 850 | -16,222 | 185 | -31,623 | 280 | -28,007 | 75 | |
| * Local other tree poles | -1,804 | 850 | -1,072 | 185 | -1,041 | 280 | -681 | 75 | |
| * Prosopis charcoal | 3,850 | 850 | 13,209 | 185 | 4,133 | 280 | 3,323 | 75 | |
| **9. Use of fencing and animal sheds:** | **-480,138** | | **-266,260** | | **-89,907** | | **-27,548** | | **-863,853** |
| * Prosopis fencing along the agri fields | -93,182 | 1 | -125,455 | 1 | -5,348 | 1 | 0 | 0 | |
| * Prosopis trees/built goat/sheep sheds | -20,323 | 1+849 | -435 | 185 | -338 | 250 | -337 | 75 | |
| * Prosopis trees or built cow shades | -128 | 850 | -326 | 185 | 0 | 0 | -31 | 75 | |
| **10. Impact on livelihoods at unprotected sand edge without prosopis:** | negative | | negative | | negative | | negative | | **Negative** |
| * Net income reduction for merchants, labour; | | | | | | | | | |
| * Education in sand invasion households reduced; | | | | | | | | | |
| **11. Loss of income due to social visiting:** | **-2,052,036** | | **-139,351** | | **-317,453** | | **-156,656** | | **-2,665,496** |
| * Loss of income-earning due to sand-induced social visiting | -2,414 | 850 | -753 | 185 | -1,270 | 250 | -2,089 | 75 | |
| **12. Sand-induced social visiting costs:** | **-32,667,200** | | **-6,679,567** | | **-1,076,000** | | **-1,666,466** | | **-41,417,541** |
| * Travel to Khartoum | -19,928 | 850 | -16,839 | 185 | 0 | | -11,521 | 75 | |
| * Travel to Shendi | -18,504 | 850 | -15,636 | 185 | -10,760 | 100 | -10,698 | 75 | |

| | | | | | |
|---|---|---|---|---|---|
| **13. Landscape aesthetics:** | positive | probably positive | probably positive | probably positive | **Positive** |
| * Prosopis good or bad (1 - 5) | | | | | |
| * Prosopis beautiful or ugly (1 or 2) | | | | | |
| | | | | | |
| **14. Health and mobility issues:** | -1,419,808 | | | | **-1,419,808** |
| * Reduced insomnia problems at sand edge | Calculated as shadow project for  for nursery, planting and shelterbelt establishment espanded to cover length of whole framed area | | | | |
| * Reduced health vulnerability | Expenses increases by Alternative B. for the new shelterbelt. | | | | |
| * Reduced allergy/respiratory diseases | Same | | | | |
| * Stabilized soil for mobility | Description in text separately, although also part of the above | | | | |
| | | | | | |
| **15. Rehabilitation of soil and land:** | Combined with 14. Health issues | | | | **0** |
| * Reduce sandstorm intensity/frequency | Calculations for nursery, planting and shelterbelt establishment | | | | |
| * Stablized soil and vegetation | Same | | | | |
| * Reduced runoff/improved soil porosity | Same | | | | |
| | | | | | |
| **16. Biodiversity of riverine area:** | greatly reduced | greatly reduced | greatly reduced | greatly reduced | **Negative** |
| | | | | | |
| **17. Historical/archaeological sites protection:** | | will be burried in sand | | will be burried in sand | **Negative** |
| **18. Prosopis related direct expenses:** | 0 | 0 | 0 | 0 | **0** |

**Table 32. Total Economic Value (TEV) analysis for Scenarios A, B and C for the Gandato Scheme framed area.**

| | **Scenario A** | **Scenario B** | **Difference A-B** | **Difference C-B** Recombining of A&B Scenarios |
|---|---|---|---|---|
| 1. Annual loss in housing quality due to sand invasion: | -41,354,830 | -93,493,886 | 52,139,056 | 93,043,888 |
| 2. Annual sand excavation needs: | -2,832,000 | -9,840,000 | 7,008,000 | 9,840,000 |
| 3. Annual rebuilding of house costs: | -7,859,725 | -22,991,165 | 15,131,440 | 22,991,165 |
| 4. Moving house site in village: | -1,013,000 | -5,672,800 | 4,659,800 | 5,672,800 |
| 5. Microclimate for crops improved: | -23,450,975 | -42,211,755 | 18,760,780 | 42,211,755 |
| 6. Livestock fodder externalities: | -65,343,060 | -551,185,550 | 485,842,490 | 549,271,622 |
| 7. Milk & meat prices lower/stable: | Positive | Negative | Positive | Positive |
| 8. Conservation of local acacia forests: | 216,464,680 | -34,715,780 | 251,180,460 | 215,866,606 |
| 9. Use of fencing and animal shades: | 396,710 | -863,853 | 1,260,563 | 722,138 |
| 10. Impact of prosopis on livelihoods at unprotected sand edge: | Positive | Negative | Positive | Positive |
| 11. Loss of income due to social visiting: | -2,052,036 | -2,665,496 | 613,460 | 2,665,496 |
| 12. Sand-induced social visiting costs (travel costs): | -17,189,513 | -41,417,541 | 24,228,029 | 41,417,541 |
| 13. Landscape aesthetics: | 0 | Positive | Positive | Positive |
| 14. Health and mobility issues: | -1,078,454 | -1,419,808 | 341,354 | 1,416,888 |
| 15. Rehabilitation of soil and land: | Part of previous | Part of previous | Part of previous | Part of previous |
| 16. Biodiversity of riparian area: | Positive | Negative | Positive | Positive |
| 17. Protection of historical/ archaeological sites: | Positive | Negative | Positive | Positive |
| 18. Prosopis related direct expenses: | -17,808,320 | 0 | -17,808,320 | -18,931,770 |
| **TOTAL SUDAN DINARS (SD)** | | | **843,357,112** | **966,188,129** |
| TOTAL EUROS (€) | | | 2,667,324 | 3,067,264 |
| **Benefit/ Cost Ratio:** | | | **46** | **50** |
| **Average household net benefit from prosopis (SD):** | | | **606,732** | **695,099** |

Figure 15. Prosopis charcoal production at an irrigation canal in the Debeira subsection of the New Halfa Irrigation Scheme. Charcoal production is an important form of livelihood for numerous landless households living in the scheme.

Figure 16. Irrigation canals in the New Halfa Irrigation Scheme before the prosopis eradication campaign started. As can be seen it is not only prosopis that obstructs the flow of water in the canals.

Figure 17. Prosopis was introduced in the 1960s as a shelterbelt for the “old nursery” horticulture orchard in the Debeira Section of the New Halfa Scheme. In 2004 this was the only place in the whole section with no invasion of prosopis.

Figure 18. Young prosopis seedlings of less than half a metre in height should be eradicated from farmlands using fire. Taller prosopis trees need to be cut and the stumps dug out, as otherwise the stumps and roots will start resprouting.

Figure 19. Overview of an irrigation scheme south of Shendi. To the far left is a prosopis bufferzone area and to the right is the Nile. The fields in the picture are irrigated with Nile water. In front typical houses are seen which are similar to those found in most villages of the Gandato Scheme.

Figure 20. Sand dunes and sheet sand can completely cover villages and town suburbs at many locations in Sudan. Here parts of a village are covered by some 3 – 3.5 m of sand and the street lies now at the roof level.

Figure 21. Sand-invaded streets are difficult to use. Some prosopis trees have established themselves in the loose sand which the roots can easily penetrate.

Figure 22. In the early 1990s, a huge sand dune was stopped by a prosopis shelterbelt from covering the Al Abdutab village opposite Shendi town across the Nile. The remnants of the original dune can be seen behind the shelterbelt. The village was forced to move in the 1930s and the 1960s due to this sand dune, and the former village now lies under the sand behind and under the shelterbelt.

Figure 23. The main part of Wad Killian village outside the Gandato Irrigation Scheme south of Shendi is protected by a shelterbelt consisting of three rows of 2 – 3 m tall prosopis shrubs with a total length of some 600 m. The sand particles are able to penetrate the shelterbelt, but as the wind speed is reduced the sand only accumulates in a 3 m high wall just inside the shelterbelt and thus the village is protected from further sand encroachment.

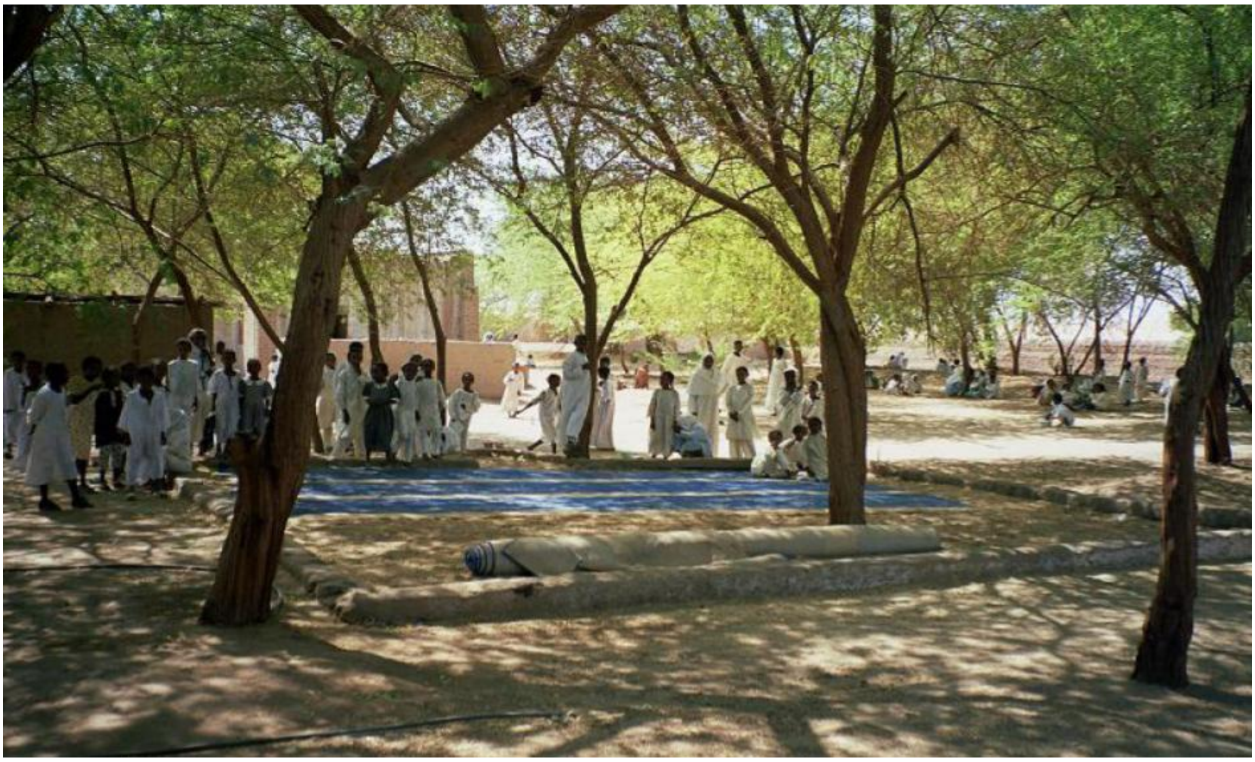


Figure 24. Children play under the shade of tall prosopis trees in a schoolyard in the Dongola suburbs.

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**ISBN 978-952-10-3891-4 (paperback)**
**ISBN 978-952-10-3892-1 (PDF)**
**ISSN 0786-8170**
**Helsinki 2007**
**Hakapaino Oy**